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ECOLOGICAL STUDIES OF THE PROPOSED KIKET ISLAND NUCLEAR POWER SITE

by

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Robert H. Burgner

Director

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1.0 SUMMARY AND CONCLUSIONS

The fisheries and marine ecology in the vicinity of Kiket Island, located in northern Skagit Bay, Skagit County, Washington have been investigated by the Fisheries Research Institute since 1969. This is the first thermal power site in Puget Sound on which comprehensive investigations have been conducted. A 1,000 MW_e nuclear power plant was proposed with a once-through cooling system which would require about 1,500 cfs of cooling water with an increase in temperature of about 10 C (18 F). A potential environmental impact may result generally from construction activities, intake operation, biofouling control methods, hydraulic effects and thermal effects. These studies were designed to assess and predict the ecological significance of these various potential impacts upon the fisheries and marine ecology of north Skagit Bay and to develop solutions to the most critical impact.

The studies of the great variety of marine organisms at the site were divided into functional groups of organisms by association as well as those groups which may be specifically vulnerable to a particular aspect of a once-through cooling system. Study priorities were established by attention to the "worst case" which might be detrimental to the most vulnerable species with recognized importance in the sport or commercial fishery. The critical stages in the life history, size and timing as well as the relative abundance in time and space were important objectives for the species with regeneration times of one year or longer. The community ecology of the marine fishes and invertebrates was investigated in detail in order to develop baseline information upon which future changes whether natural or man caused may be assessed.

This investigation has researched the following specific areas: the seasonal changes in water quality in north Skagit Bay, juvenile salmonid migration, pelagic eggs and larval fishes, intertidal and subtidal community ecology, marine fish species diversity, thermal effects on fish and invertebrates, toxicity of chlorine and heat, marine fouling of artificial substrates, qualitative evaluation of marine zooplankton and the potential of heated water in salmonid mariculture. The development of a 1,000 MW_e nuclear power plant at this site will create some localized changes in the marine ecosystem; however, the only problem of ecological significance is posed by the potential entrainment of the economically important juvenile salmonids (i.e., pink and chum

salmon). These species alternate in annual dominance and occur in dense numbers around Kiket Island for about three months each spring during their migration to sea. Because of their small size [mean length about 35 mm (1.4 inch)] and delicate nature, passage through the cooling system may not only cause direct mortalities but also induce some behavioral alterations among the survivors making them highly vulnerable to the natural fish predators in the Bay. An intake screening system of small enough aperture to prevent the passage of these juvenile salmonids through the plant is essential. Due to the fineness of the mesh this may require an intake screening system of unique design to avoid impingement problems usually associated with screening.

There are at least two possible approaches to the design and placement of a once through cooling intake structure in this area which would minimize the entrainment of juvenile salmon. The surface orientation of about 90 per cent of the juvenile pink, chum, and chinook salmon to the upper 10 ft of the water column would logically dictate the placement of an intake equipped with a low velocity design to draw cooling water from a horizontal direction at a depth of approximately 60 ft. However, it is likely that large numbers of juvenile resident pelagic marine species (i.e., smelt and herring) or demersal marine fishes may be entrained in a deep intake and thus a fish screening and return system would be required on shore. An alternative approach is to develop a positive solution to the entrainment and impingement of larval and juvenile fishes, a problem common to all water use industries. Associated with this project has been the on-site testing of a model rapid sand filter to determine the design parameters necessary in applying this concept as a positive solution to the entrainment of larval and juvenile fishes. This work is detailed in a separate report by Stober, Hanson, and Swierkowski (1973). An engineering design concept was developed from this study by Strandberg (1972) for a high capacity sand filter which would provide an effective solution to the entrainment and impingement of small fishes and thus solve the only problem of major significance to the marine ecosystem at this site.

The predicted increased temperatures expected to result in the Bay from this 1,000 MW_e plant compared to all the thermal effects studies conducted in the on-site laboratory during the past three years on invertebrates as well as fish indicate that the increased temperatures will not be a problem of ecological significance with proper discharge design and location.

2.0 ACKNOWLEDGMENTS

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3.0 PREFACE

This report contains the scientific results of the ecological studies conducted by the Fisheries Research Institute on the Kiket Island nuclear power site proposed by Seattle City Light and the Snohomish County Public Utility District in 1969. The organization of this report is by subproject dealing with the physical conditions of the marine environment, specific problems associated with once-through cooling systems and a discussion of the marine fish and invertebrates which occupy the various marine habitats. This constitutes the final report of these comprehensive studies to the sponsoring utilities, however, five graduate theses will be available in restricted numbers as a result of graduate student support furnished during the course of this project. Additional details may be found in these as well as in two preceeding annual reports by Stober and Salo (1970 and 1971), however, an effort has been made to include all significant results and conclusions in this final report.

4.0 SEASONAL WATER QUALITY IN NORTH SKAGIT BAY

by

Q. J. Stober, S. J. Walden and D. T. Griggs

4.1 INTRODUCTION

Water quality data were taken at the Kiket Island Laboratory and over the study area in conjunction with townet sampling operations during the study period 1970-72. These data have a direct bearing on the biological studies and are presented in support of certain biological conclusions. To avoid unnecessary duplication only data taken by project personnel in the execution of the biological investigations are presented. The University of Washington Department of Oceanography and the Applied Physics Laboratory were responsible for a detailed study of the physical oceanography of this site.

4.2 MATERIALS AND METHODS

Ambient water temperatures were recorded continuously from April 13, 1970 to September 20, 1972 in the Kiket Island Laboratory, as well as from thermisters placed at the surface and on the bottom 250 m off the south shore and 150 m off the north shore of the island. Sea water was pumped from a depth of about 3.1 m (10 ft) MLLW in Similk Bay. The temperature was monitored continuously in the laboratory with an electronic thermometer (ARA-ET100A), a 20-input, programmable scanner (ARA-SD20), and a strip chart recorder (ARA-400). Hydrographic temperature probes (Model L5U-SF) were used.

Laboratory salinity measurements were taken intermittently beginning May 18, 1970 and ending September 20, 1972. Salinity measurements were made with a conductivity meter (ARA-TC), a salinometer (Beckman model RS-5), a Goldberg Refractometer standardized to known NaCl solutions, and routinely compared against analyses by the University of Washington Department of Oceanography. Despite the variety of techniques used, reproducibility was within $\pm$ 1 ppt.

Mean surface water temperature, visibility, dissolved oxygen, and salinity were measured in 0.46 km^2 (1/4-square nautical mile) grid sections in Similk Bay, North Skagit Bay, and the Swinomish Channel during the 1971 and 1972 tow-net seasons and in Similk Bay and North Skagit Bay during the 1970 tow-net season. The Swinomish Channel was not sampled during the 1970 operations. Surface water temperatures and salinity were measured with an RS-5 salinometer. Dissolved oxygen content was determined through the Alsterberg modification of the standard Winkler titration. Visibility was approximated with a 20-cm Secchi disc while the boat was underway. Samples were taken during surface trawling and purse seining.

4.3 RESULTS AND DISCUSSION

4.3.1 Kiket Island Laboratory Data

Mean weekly laboratory water temperatures are summarized for the period beginning April 13, 1970 and ending August 28, 1972 in Fig. 4-1. Mean weekly laboratory temperatures reached a maximum of 11.9 C during July and August 1971, and 11.8 C during the same period in 1972. Similarly, maximum offshore surface temperatures reached 17.4 C during 1970, 17.3 C during 1971, and 18.8 C during 1972. A minimum offshore temperature of 3 C was observed during January 1971 and a similar reading of 4.5 C was recorded in January 1972. The larger deviation from the mean of maximum temperatures observed during June, July, and August for all three years represents surface temperature changes of short duration due to tidal mixing and circulation in the area. These temperatures indicate the near-shore maxima that are not generally observed in more thoroughly mixed offshore waters near the east end of Deception Pass (Lincoln, Collias, and Barnes, 1970). Temperature data taken aboard the R.V. *Kwntuks*, anchored offshore from the laboratory, were used from April 29, 1972 to June 9, 1972.

Weekly laboratory salinity measurements are summarized from May 18, 1970 to August 28, 1972 in Fig. 4-2. Average weekly salinities ranged from 14.5 to 29.7 ppt over this period, minimum observations of 10 and 15 ppt were recorded during February and June 1971, respectively, and observations of 14.8 ppt and 13.8 ppt were recorded during June and July 1972, respectively, during period of heavy runoff. Surface salinities taken in conjunction with

Fig. 4-1. Weekly laboratory mean, minimum and maximum and offshore minimum and maximum water temperatures recorded in the Kiket Island laboratory, 1970-1972.

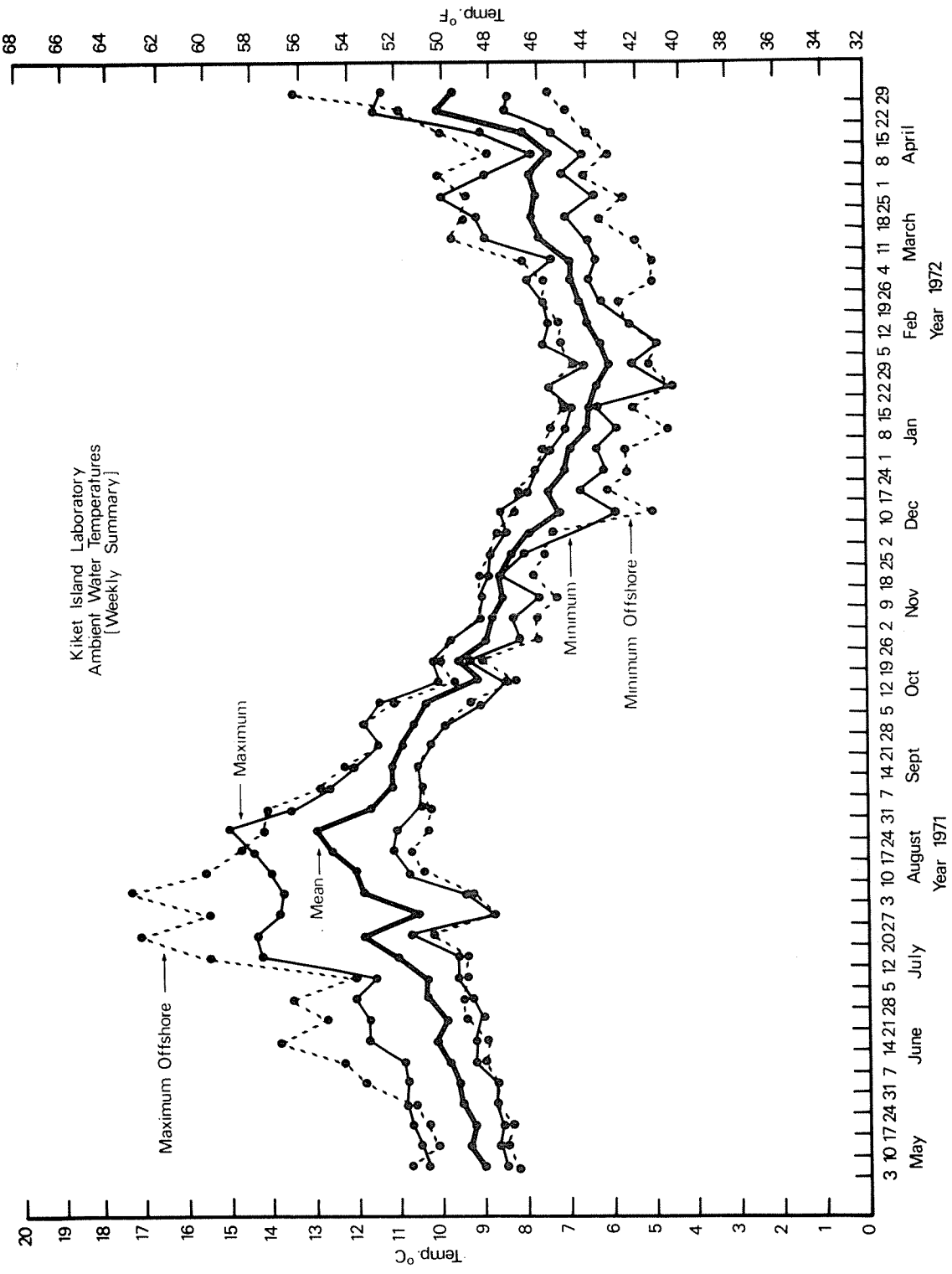

Fig. 4-1. Weekly laboratory mean, minimum and maximum, and offshore minimum and maximum water temperatures recorded in the Kiket Island laboratory, 1970-1972. (Continued)

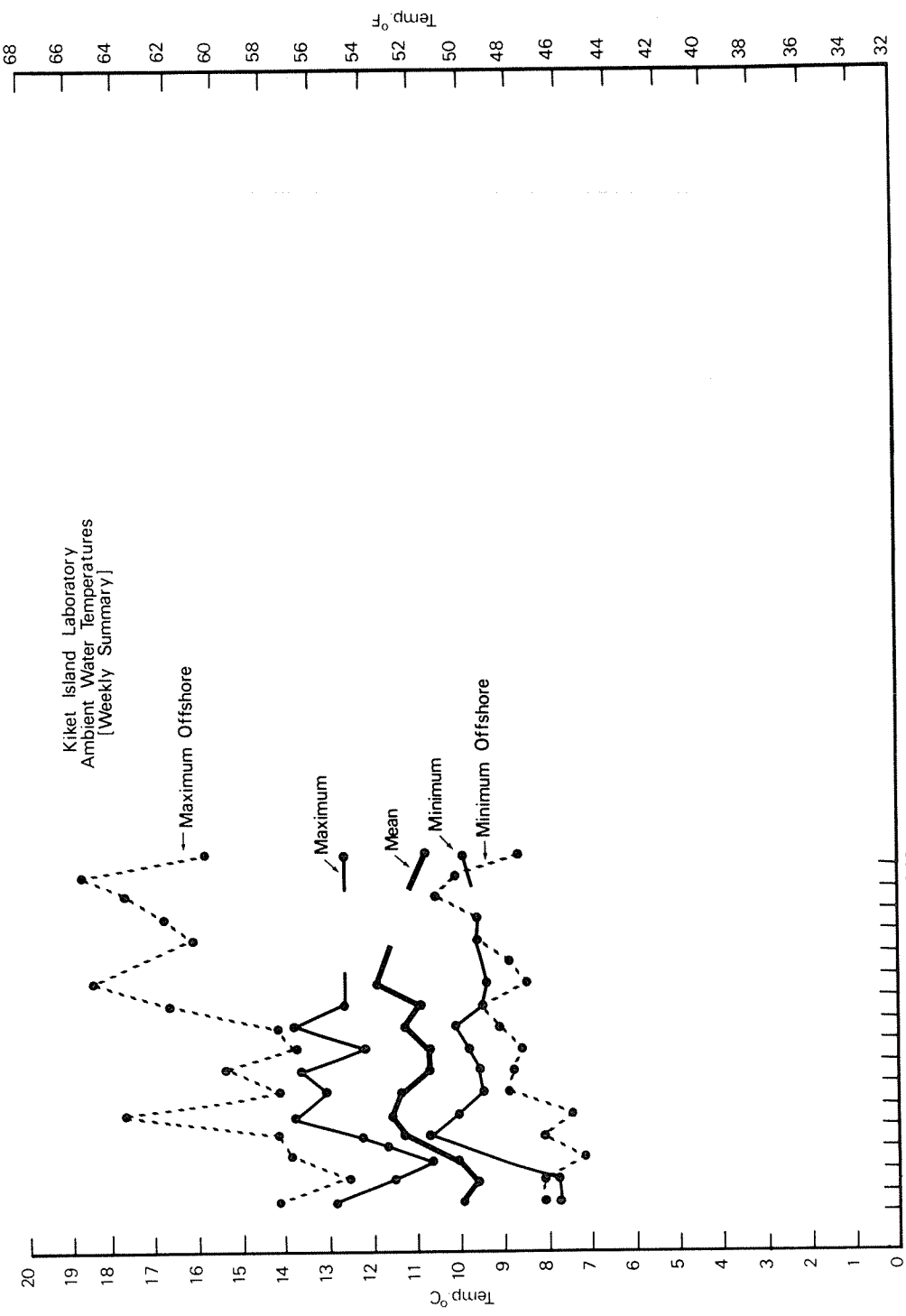

Fig. 4-1. Weekly laboratory mean, minimum and maximum, and offshore minimum and maximum water temperatures recorded in the Kiket Island laboratory, 1970-1972. (Continued)

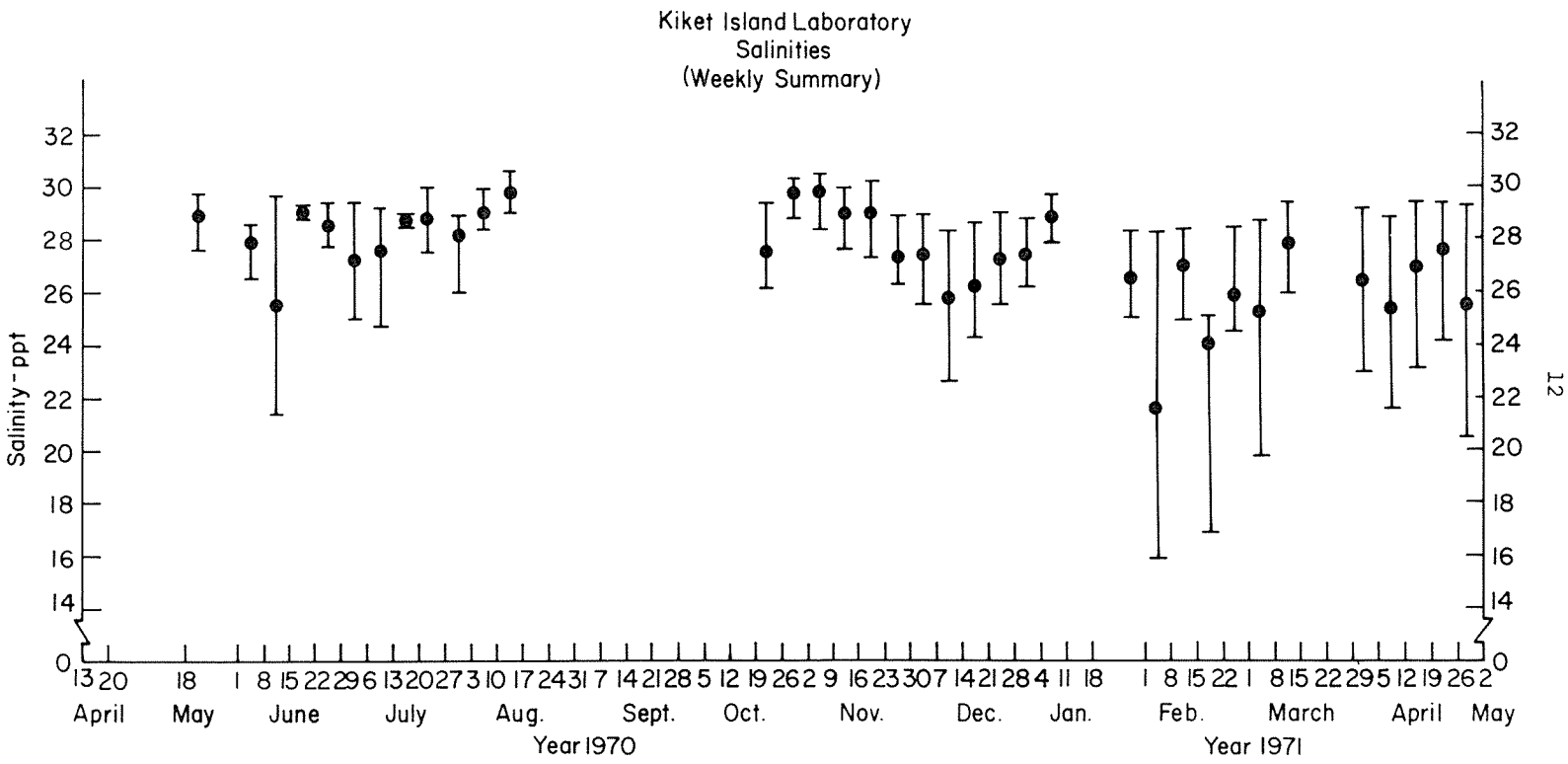

Fig. 4-2. Weekly mean, minimum, maximum salinity measurements taken in the Kiket Island laboratory, 1970-1972.

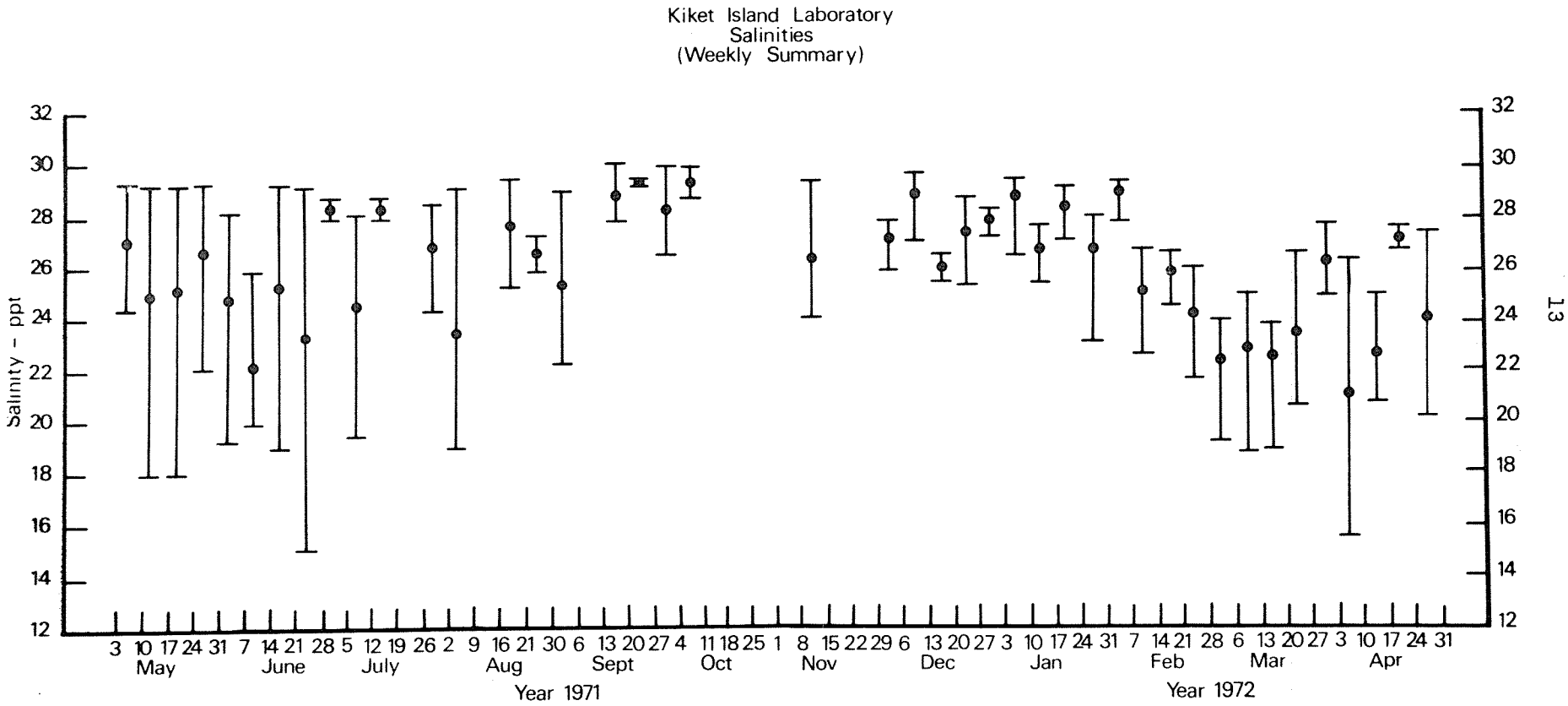

Fig. 4-2. Weekly mean, minimum, maximum salinity measurements taken in the Kiket Island laboratory, 1970-1972. (Continued)

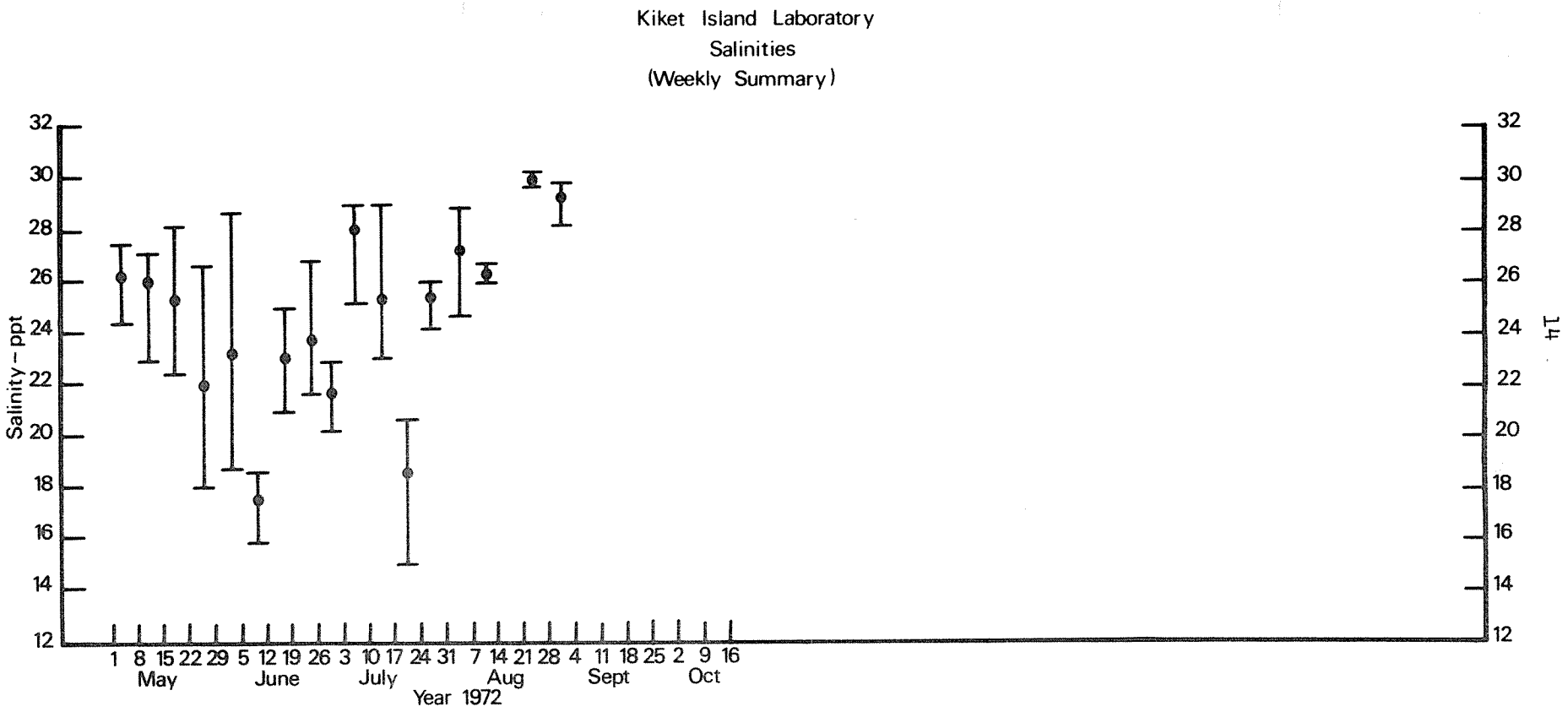

Fig. 4-2. Weekly mean, minimum, maximum salinity measurements taken in the Kiket Island laboratory, 1970-1972. (Continued)

tow net sampling and operations aboard the R.V. *Kumtuks* offshore from the laboratory were used for the period from May to August 1972 when no laboratory data were taken.

4.3.2 Skagit River Discharge

Weekly minimum, maximum, and mean discharge rates (cfs) of the Skagit River at Mount Vernon, Washington, for the period of January 1970 to September 30, 1972 are presented in Figs. 4-3 to 4-5 (U.S. Geological Survey Water Resources Division, Skagit River Discharge Data 1970-1972). The weekly mean range grew steadily greater from one year to another, reaching the greatest levels in 1972 (1970: 6,512-24,414; 1971: 6,314-45,814; 1972: 9,605-53,357). The maximum discharges in these years were 34,100 cfs during the week of April 5-11, 1970; 65,700 cfs January 31-February 6, 1971; and 73,900 cfs July 9-15, 1972. Minimum discharges of 4,550 cfs were recorded during the week of September 13-19, 1970; 5,100 cfs September 26-October 2, 1971; and 8,330 cfs January 16-22, 1972.

4.3.3 Surface Water Quality

Mean weekly surface water quality values for dissolved oxygen, visibility, salinity, and temperature by sampling area for the 1970, 1971, and 1972 sampling seasons are given in Figs. 4-6 to 4-13. Differences in mean water quality values among areas were tested by analysis of variance, and the relationship of mean weekly water quality values by sampling area to mean weekly discharge of the Skagit River (cfs) was tested for 1972 data by linear regression analysis. The sampling areas used in this section are described in Section 5.0 of this report.

During the 1972 sampling season, the mean weekly dissolved oxygen content gradually declined from a high in early April to its lowest level during a sustained Skagit River freshet in July (Fig. 4-6). The sampling area off the mouth of the Skagit River (Area IV) exhibited a significantly higher (0.01) mean weekly dissolved oxygen content than other areas; dissolved oxygen content ranged here from 10.5 to 14.9 ppm over the study period. Mean weekly dissolved oxygen content in all sampling areas was significantly (0.01) related to mean weekly discharge

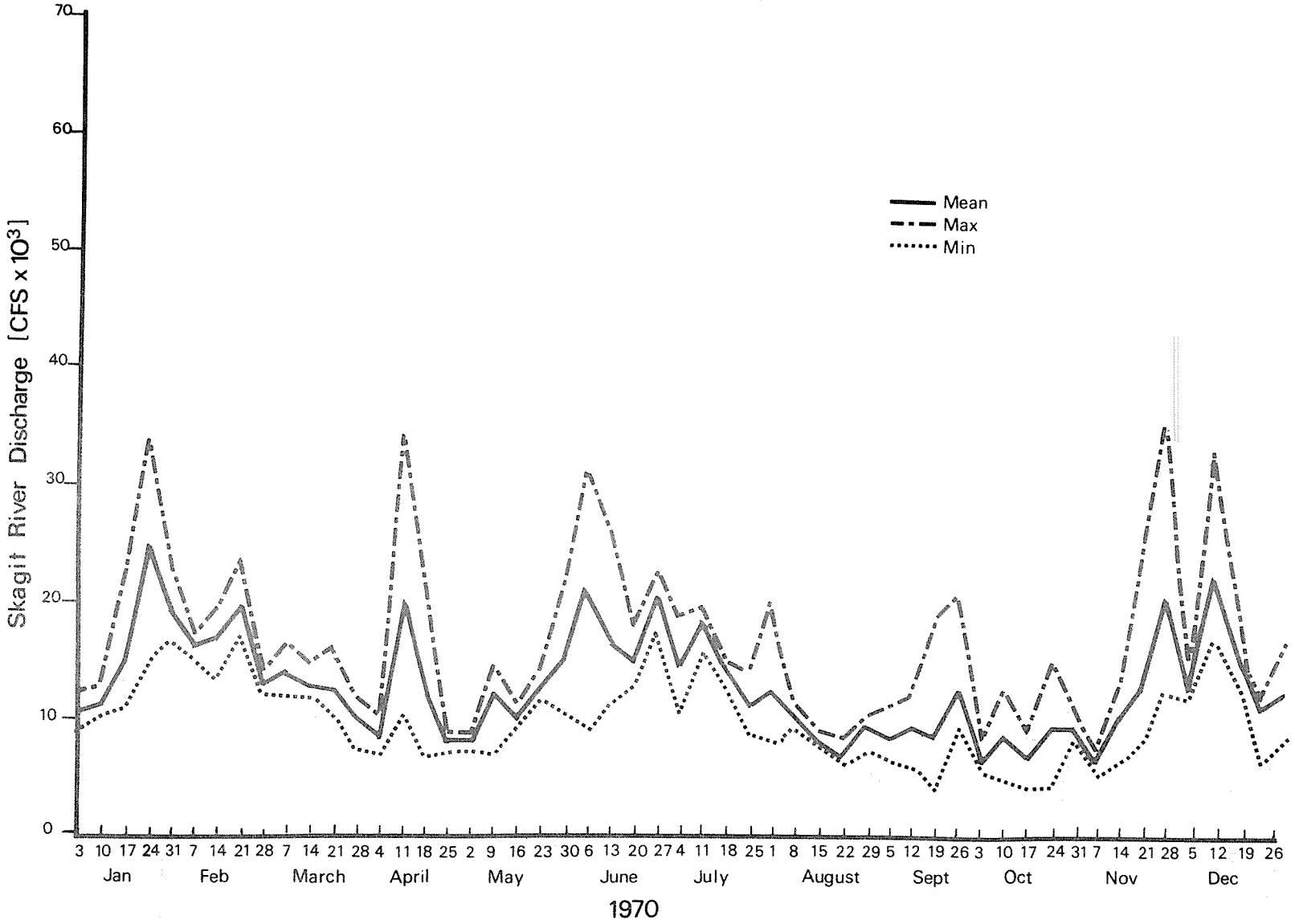

Fig. 4-3. Mean, minimum, and maximum weekly Skagit River discharge in cfs at Mount Vernon, Washington in 1970 (USGS; Water Resources Data, 1971).

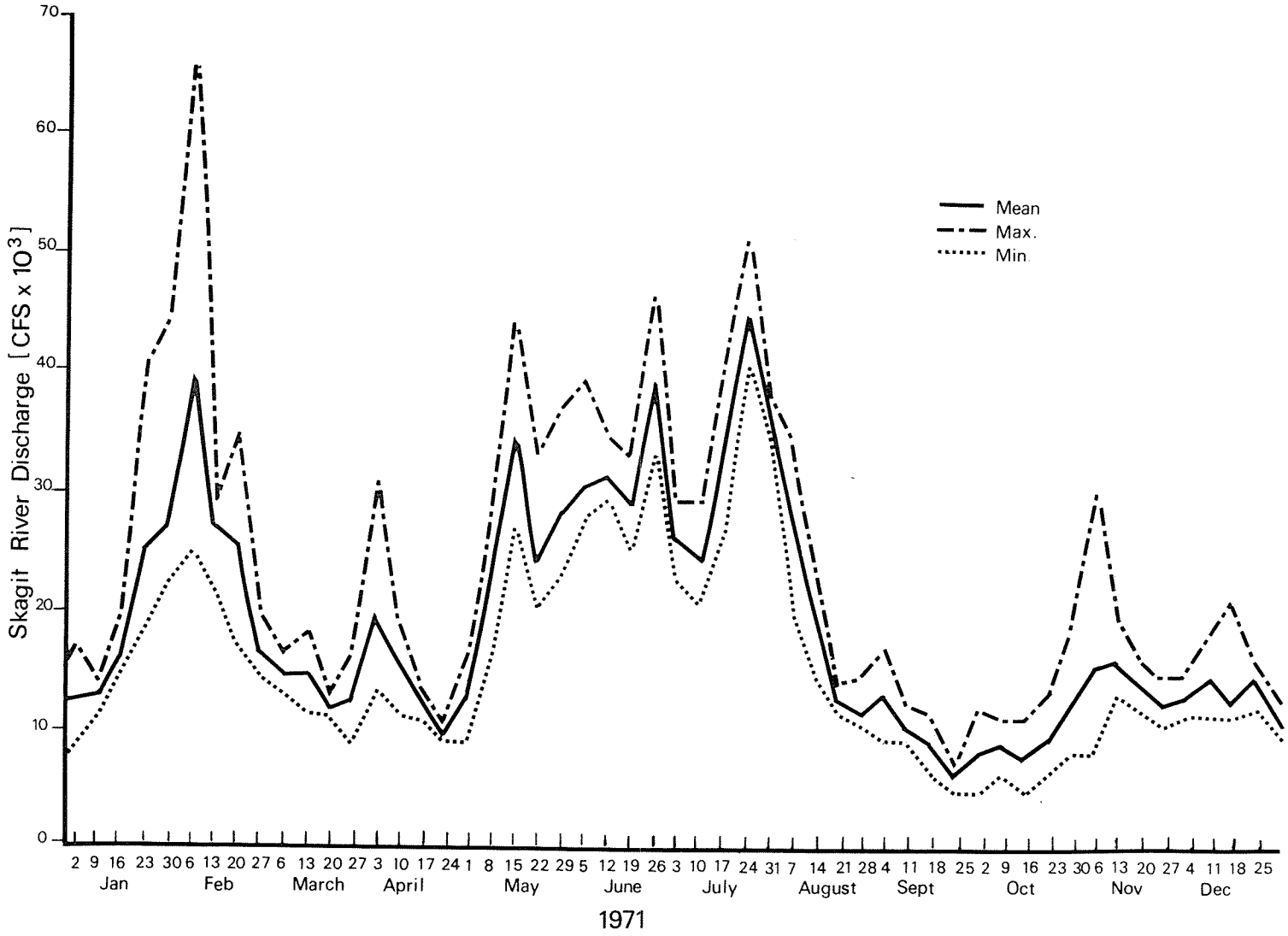

Fig. 4-4. Mean, minimum, and maxiuum weekly Skagit River discharge in cfs at Mount Vernon, Washington in 1971 (USGS, Water Resources Data, 1971).

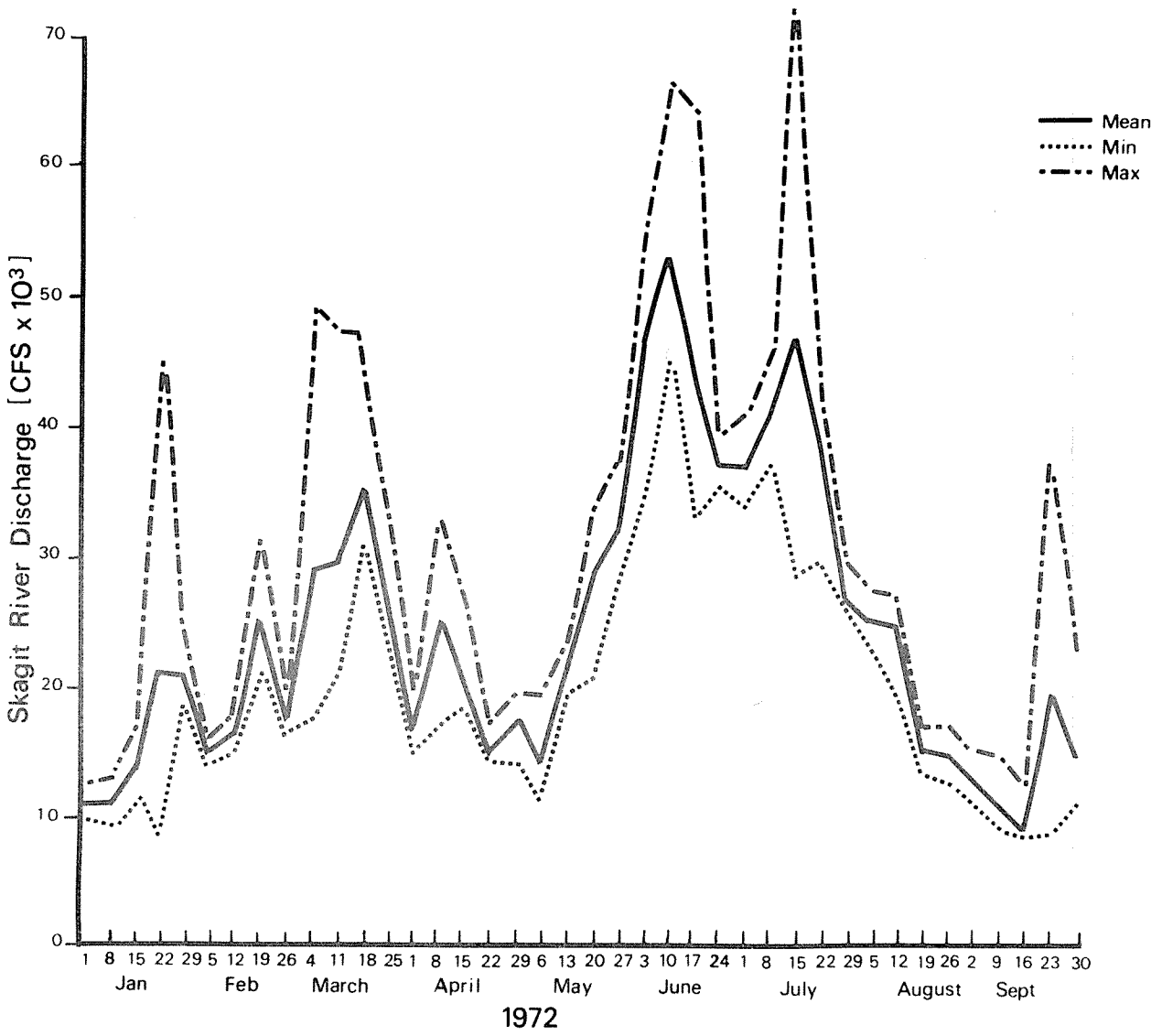

Fig. 4-5. Mean, minimum, and maximum weekly Skagit River discharge in cfs at Mount Vernon, Washington in 1972 (USGS; Water Resources Provisional Flow Data, 1972).

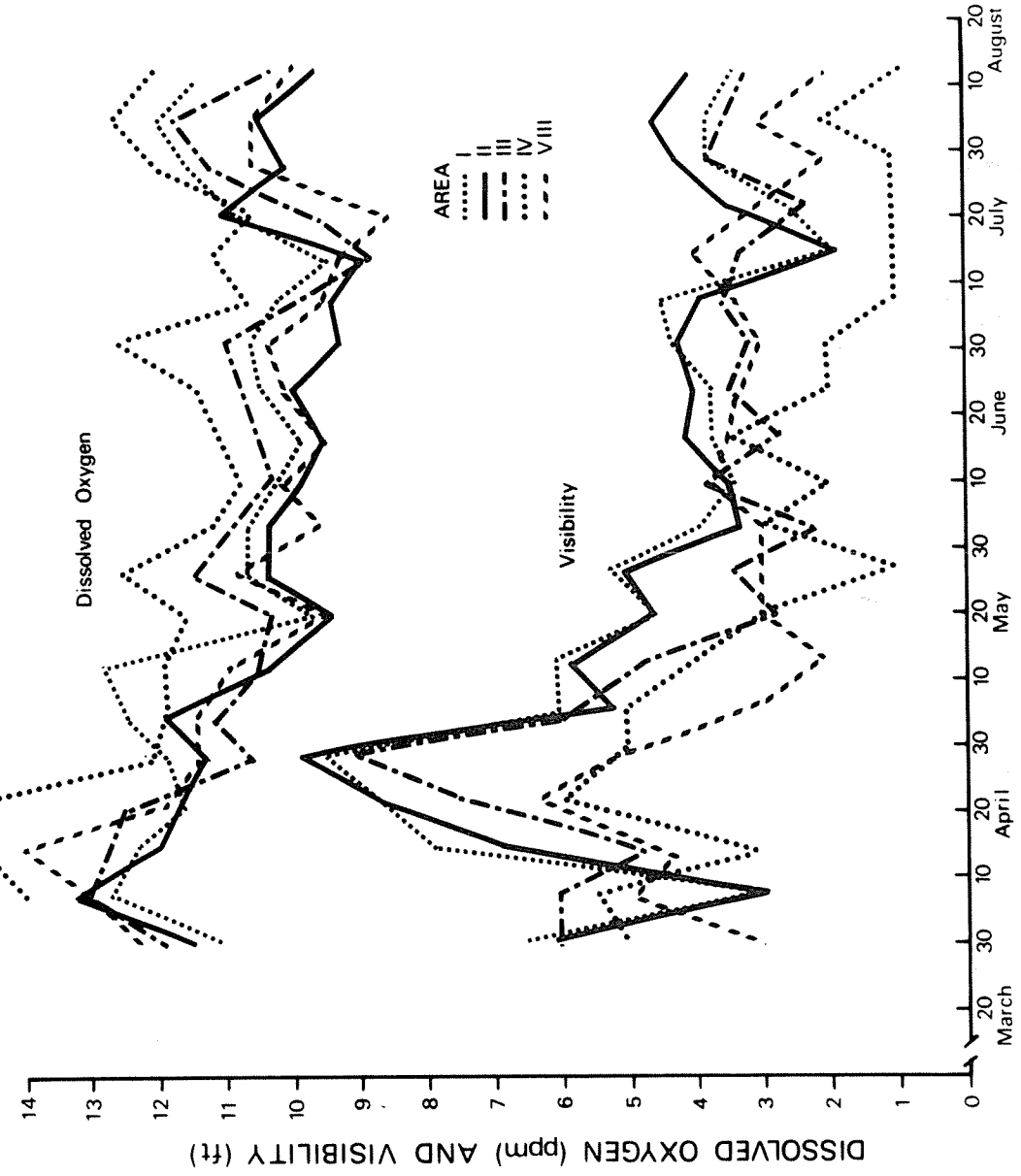

Fig. 4-6. Mean weekly surface dissolved oxygen concentrations and Secchi disc transparencies in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), off the Skagit River mouth (Area IV), and the Swinomish Channel (Area VIII), 1972.

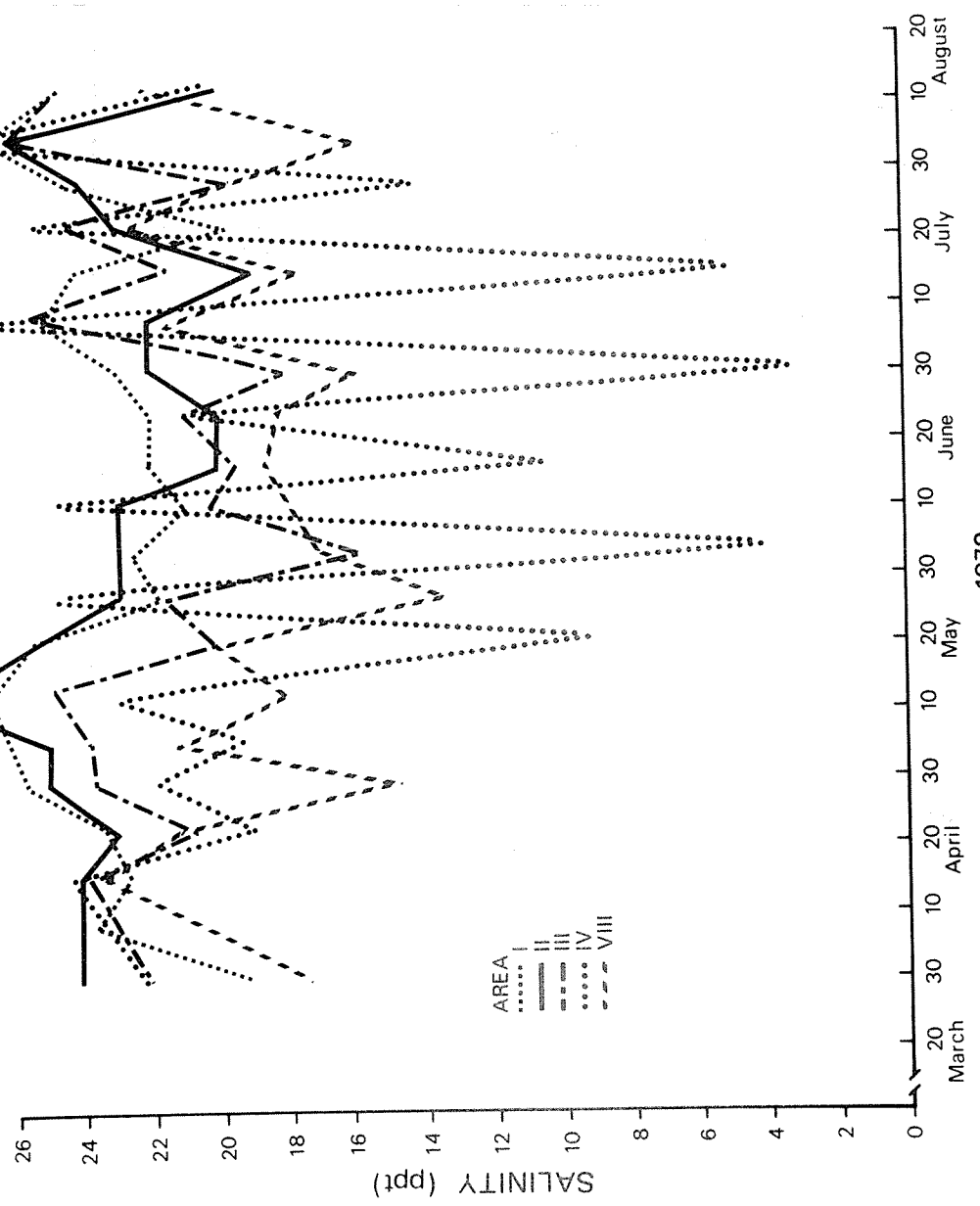

Fig. 4-7. Mean weekly surface salinities by sampling area in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), off the Skagit River mouth (Area IV), and the Swinomish Channel (Area VIII), 1972.

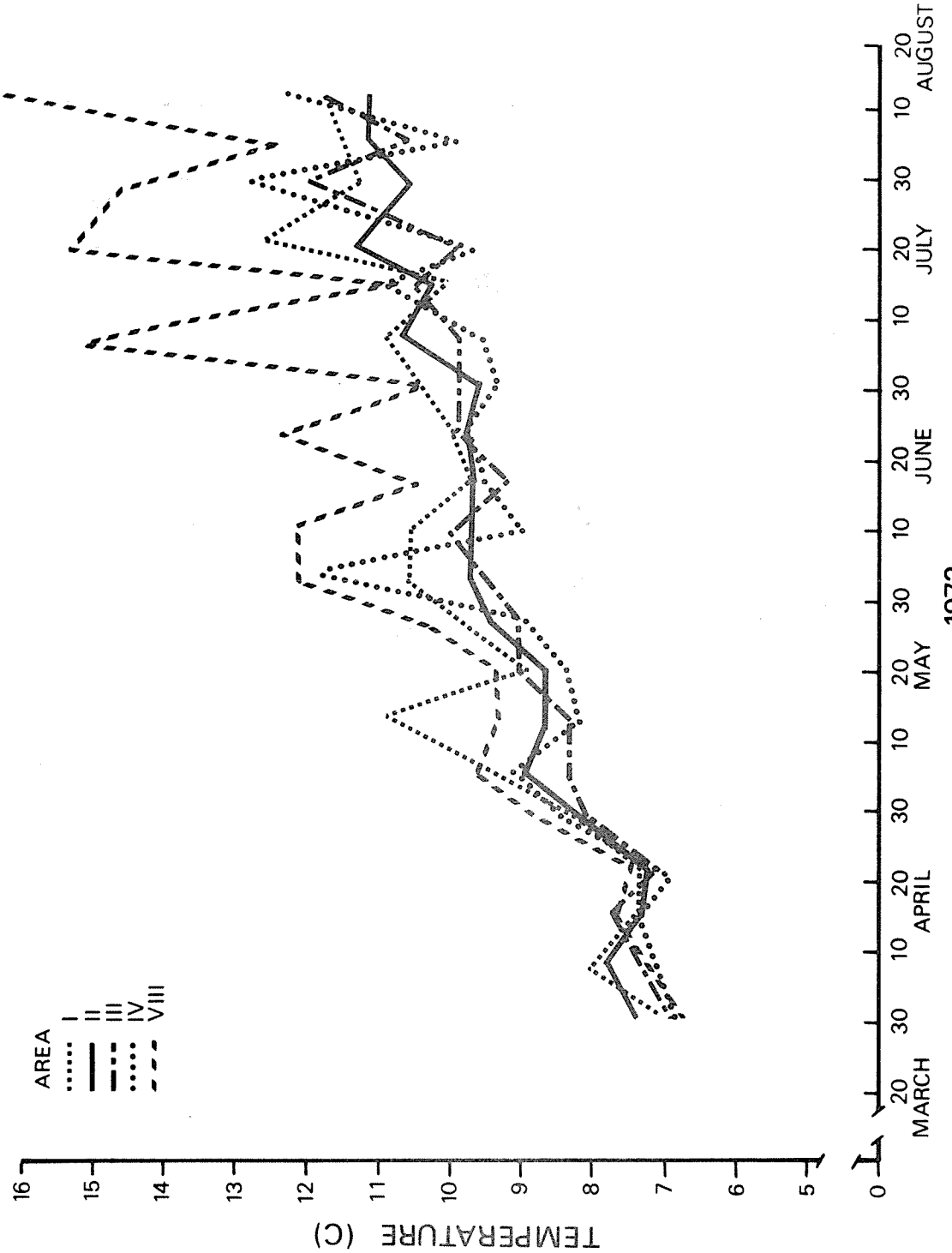

Fig. 4-8. Mean weekly surface temperatures in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), off the Skagit River mouth (Area IV), and the Swinomish Channel (Area VIII), 1972.

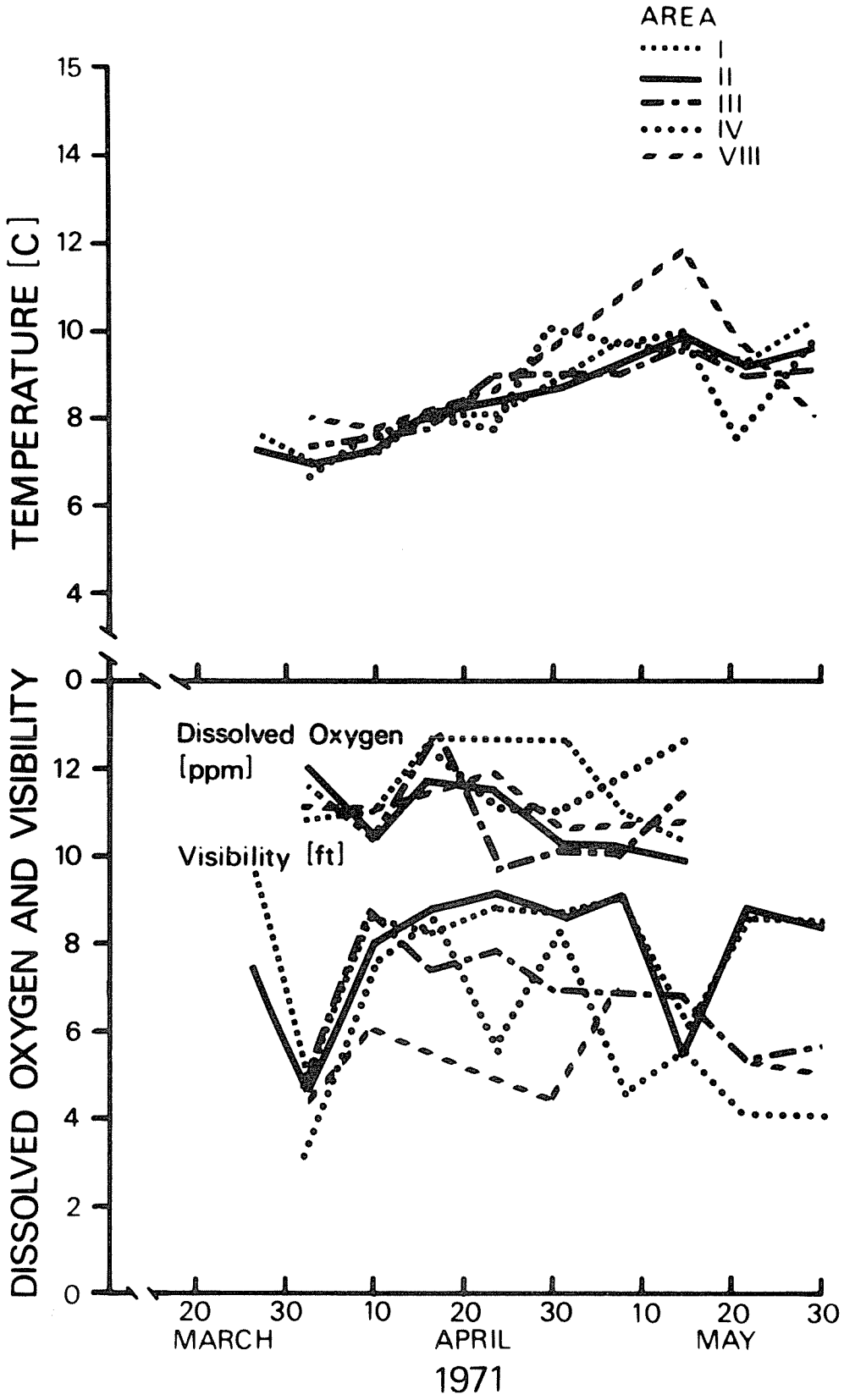

Fig. 4-9. Mean weekly surface temperatures, dissolved oxygen concentrations, and Secchi disc transparencies by sampling area in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), off the mouth of the Skagit River (Area IV), and the Swinomish Channel (Area VIII), 1971.

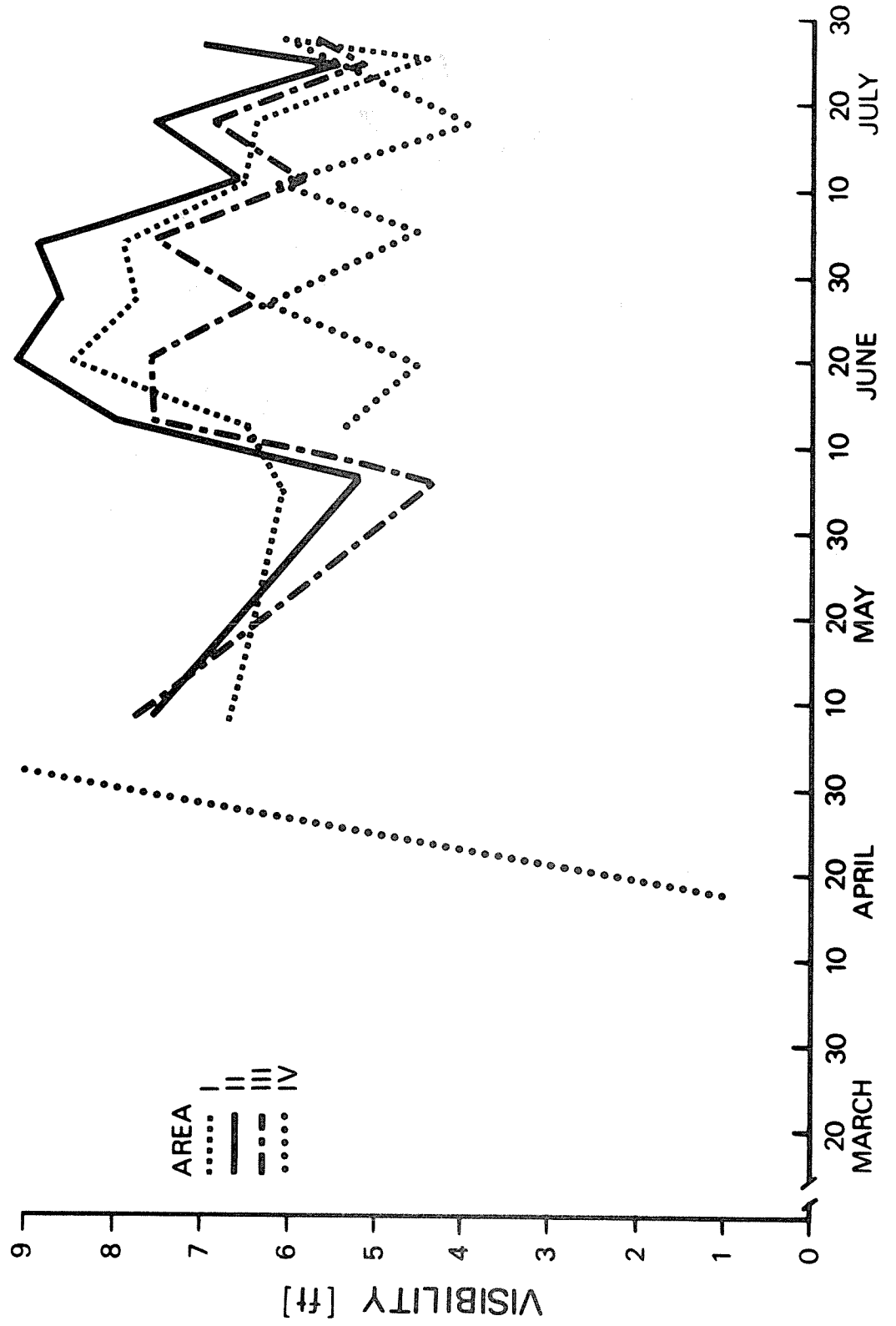

Fig. 4-10. Mean weekly surface Secchi disc transparencies in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), and off the Skagit River mouth (Area IV), 1970.

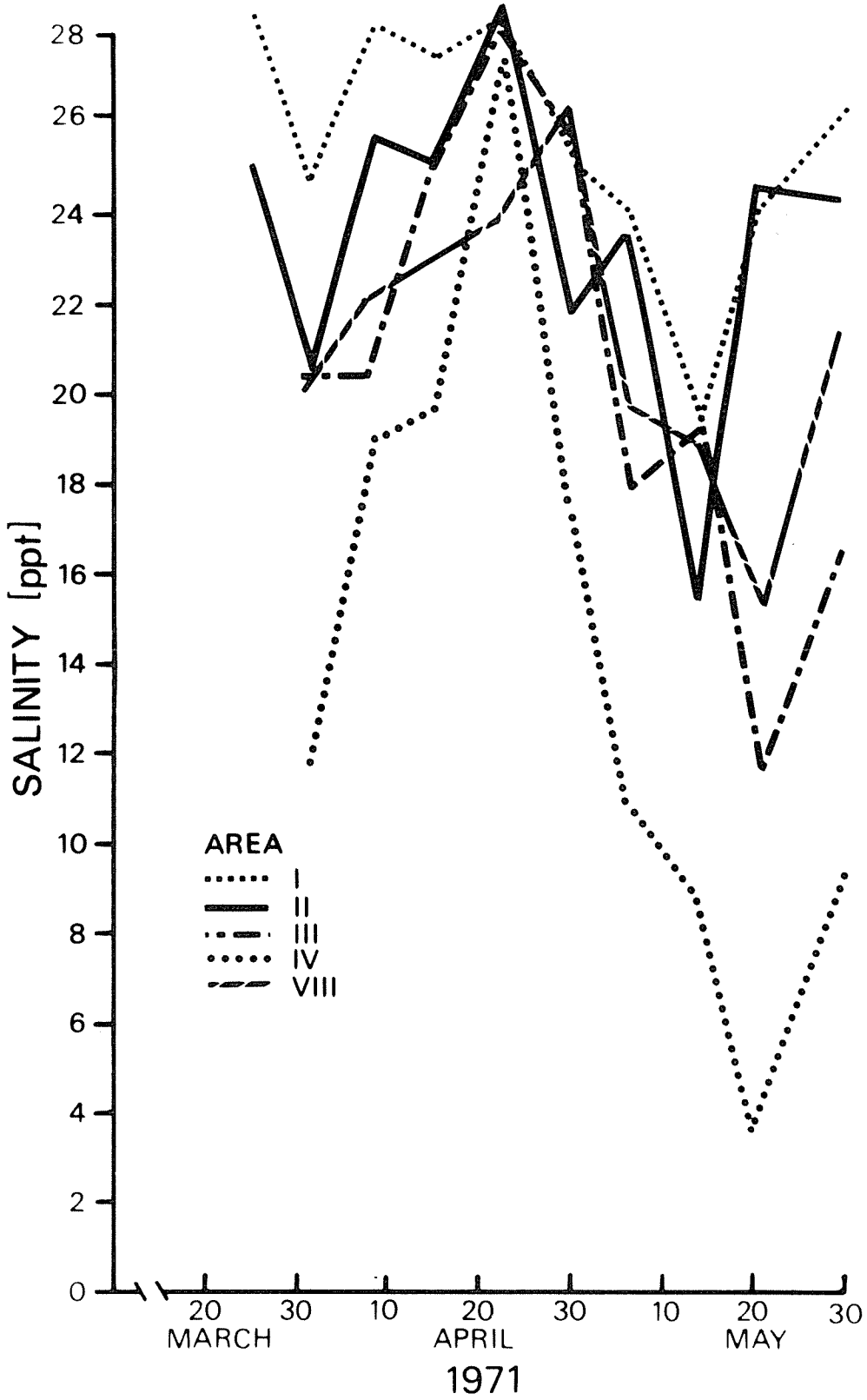

Fig. 4-11. Mean weekly surface salinities in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), off the Skagit River mouth (Area IV), and the Swinomish Channel (Area VIII), 1971.

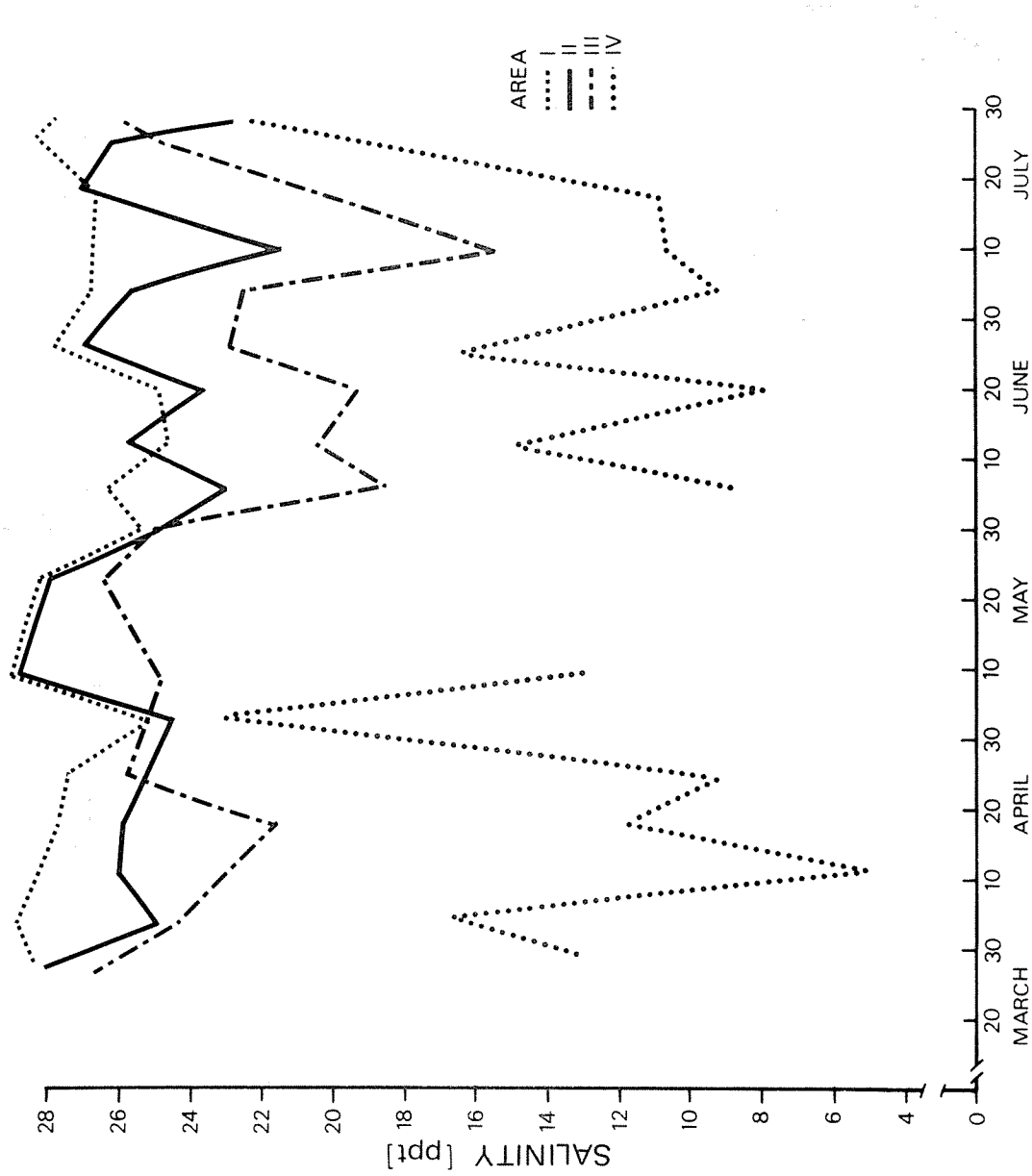

Fig. 4-12 Mean weekly surface salinities in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), and off the Skagit River mouth (Area IV), 1970.

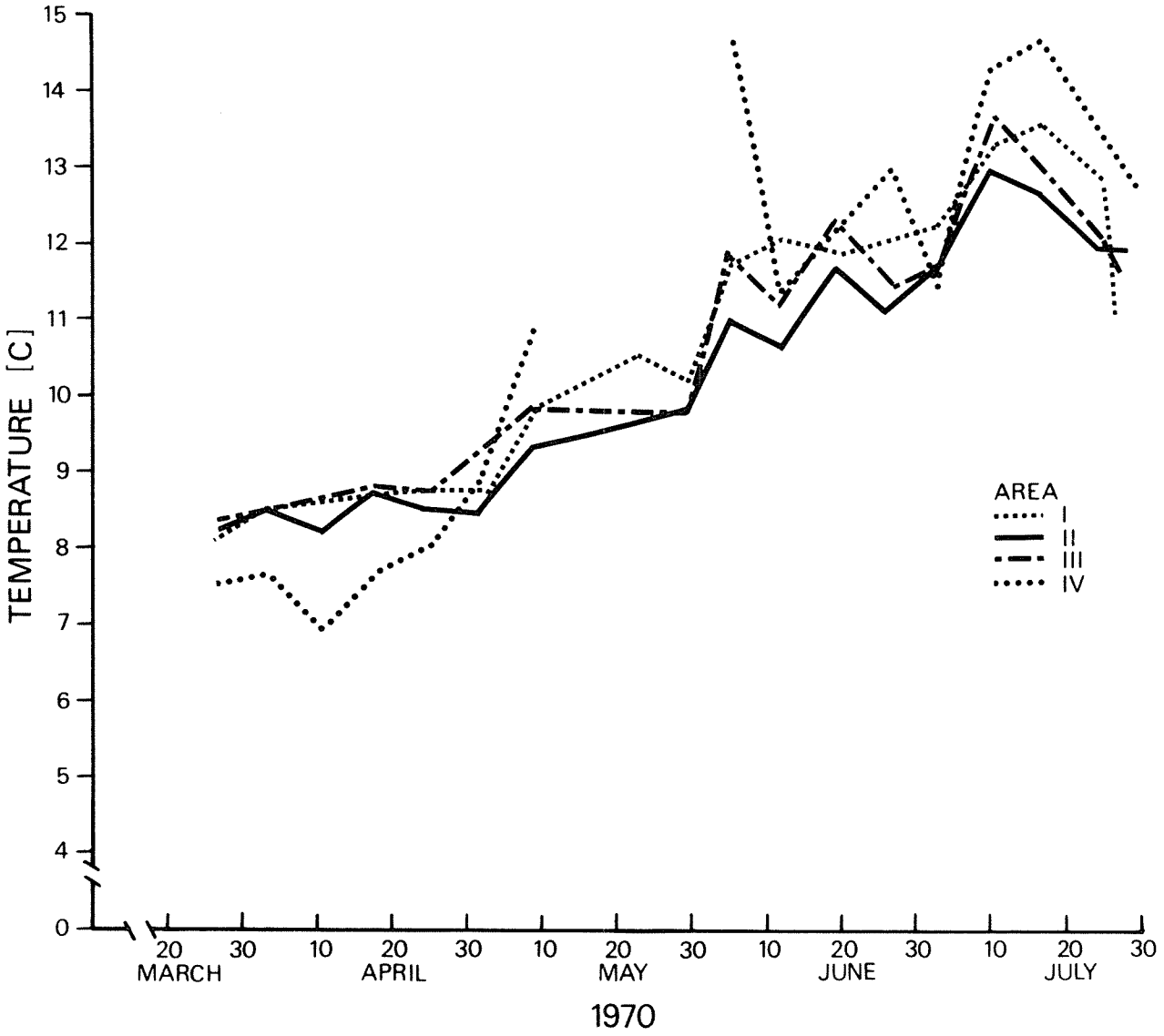

Fig. 4-13. Mean weekly surface temperatures in Similk Bay (Area I), Hope Island Bay (Area II), south of Hope Island (Area III), and off the Skagit River mouth (Area IV), 1970.

from the Skagit River. The higher dissolved oxygen concentrations observed off the river mouth are probably most related to the lower salinities as compared to generally increasing salinities in areas farther removed. This follows the inverse relationship of salinity and dissolved oxygen.

Mean weekly visibility values taken during the 1972 sampling season were significantly (0.01) lower off the Skagit River mouth and in the Swinomish Channel (Area VIII) than other sampling areas and ranged from 0.30 m to 2.43 m (1 to 8 ft) off the river mouth and from 0.61 m to 1.92 m (2 to 6.3 ft) in the Swinomish Channel (Fig. 4-6). Mean weekly visibility values declined seasonally from a high in late April to their lowest during the July freshet. All sampling areas except the Swinomish Channel showed a significant (0.01) relationship between mean weekly visibility and mean weekly discharge from the Skagit River.

Mean weekly salinity values recorded during the 1972 sampling season exhibited wide fluctuation throughout the study period, most notably during the freshet of June and July (Fig. 4-7). Mean weekly salinities were significantly lower (0.01) for the sampling area off the Skagit River and the Swinomish Channel than for other sampling areas and ranged from 3.2 to 26.6 ppt off the river mouth and from 13.4 to 23.5 ppt in the Swinomish Channel. A significant correlation (0.01) was found between mean weekly discharge from the Skagit River and mean weekly salinity values for Hope Island Bay (Area II) but not for other sampling areas. A wide range in sampling effort between Areas I and II and all other sampling areas as well as the extreme tidal influence may account for the low correlation for other areas between Hope Island Bay and the mouth of the Skagit River.

Mean weekly surface water temperatures increased seasonally during the 1972 sampling season and were highest during periods of prolonged warm and sunny weather. They were significantly warmer in the Swinomish Channel (0.05) than other areas and ranged from 6.7 to 16.4 C during the season (Fig. 4-8). Mean weekly surface water temperatures were significantly (0.05) related to mean weekly discharge from the Skagit River for all areas except Area IV off the mouth of the Skagit River. Low sampling effort in the area off the river mouth may account for this result.

In general, water quality values taken during the 1970 and 1971 sampling seasons followed the same trends as 1972 values. It should be noted that 1971 water quality data extended over a three-month period from March through May and can only be compared to the similar period of time in 1970 and 1972 data. The relationship between mean weekly water quality values and mean weekly discharge from the Skagit River was not tested statistically for 1970 and 1971 data.

Mean weekly dissolved oxygen content during the 1971 sampling season (Fig. 4-9) ranged from 9.7 ppm south of Hope Island (Area III) to 12.7 ppm in Similk Bay (Area I). No significant difference in mean weekly dissolved oxygen content was observed between areas for 1971 data. Insufficient samples were taken during the 1970 sampling season to permit weekly analysis of mean dissolved oxygen values. Mean weekly visibility values were significantly (0.01) lower south of Hope Island (Areas III, IV, and VIII) than in Similk and Hope Island Bays (Areas I and II, respectively) during the 1971 season (Fig. 4-9), and Hope Island Bay was significantly (0.05) higher in mean weekly visibility than the area off the Skagit River mouth during the 1970 season (Fig. 4-10). Mean weekly visibility values ranged from 2.59 m (8.5 ft) south of Hope Island (Area III) to 0.91 m (3 ft) off the Skagit River mouth (Area IV) in 1971 and from 2.77 m (9.1 ft) in Hope Island Bay to 0.30 m (1.0 ft) off the Skagit River mouth in 1970. Mean weekly salinity values in 1971 and 1970 showed great fluctuation, compared with 1972 data. During the 1971 season, the area off the Skagit River mouth was significantly less saline (0.01) than other areas on a mean weekly basis (Fig. 4-11). During the 1970 season, all areas south of Hope Island (Areas III and IV) were significantly less saline than Similk and Hope Island Bays and were significantly (0.01) different from each other (Fig. 4-12). Mean weekly salinities ranged from 28.6 ppt in Similk Bay to 2.7 ppt off the Skagit River mouth in 1971 and from 28.9 ppt in Similk Bay to 7.9 ppt off the Skagit River mouth in 1970. Mean weekly surface water temperatures taken during the 1970 and 1971 sampling seasons showed similar seasonal increases as found in 1972 data. No significant difference in mean weekly surface water temperature was observed between sampling areas for 1970 or 1971 data. Mean weekly surface temperatures ranged from 11.9 C in the Swinomish Channel to 6.7 C

off the mouth of the Skagit River during 1971 (Fig. 4-9) and from 6.8 C to 14.6 C off the Skagit River mouth during the 1970 season (Fig. 4-13).

The influence of the Skagit River on the mean weekly water quality of North Skagit Bay, Similk Bay, and the Swinomish Channel was most apparent during conditions of flood. During all three sampling seasons flooding occurred with the spring and summer freshet from April until the end of July. Highest mean monthly discharges occurred in June 1970 (18,890 cfs), July 1971 (33,960 cfs), and June 1972 (43,460 cfs) near Mount Vernon, Washington (USGS Skagit River Discharge Data, 1970-72).

Surface salinity contours were drawn for Similk and Hope Island Bays from surface observations on selected days to illustrate the changes due to high and low Skagit River discharge on surface salinities during flood tide and ebb tide (Figs. 4-14 to 4-17). During flood tide and high discharge from the Skagit River, estuarine water freshened by the river is seen in sharp contrast to highly saline tidal water originating from outside Deception Pass and sharp salinity contour patterns develop where the two water masses meet (Fig. 4-14). The effect is less pronounced on ebb tide than flood tide (Fig. 4-15). During low discharge from the Skagit River, a more homogeneous salinity pattern is seen at flood tide and ebb tide (Figs. 4-16 and 4-17). Tidal currents during flood tide and ebb tide shown were taken from the University of Washington Department of Oceanography data (Lincoln, Collias, and Barnes, 1970).

4.4 SUMMARY AND CONCLUSIONS

Three main factors, namely the level of discharge of the Skagit River, tidal exchange through Deception Pass, and seasonal air temperatures, strongly influenced the four water quality parameters measured, i.e., dissolved oxygen, salinity, temperature, and turbidity. It is the interaction of these factors which determined the observed values. The Skagit River significantly affects the surface water quality of North Skagit Bay, Similk Bay and to a lesser degree the Swinomish Channel. During periods of high river discharge, salinity and visibility generally increase with an increase in distance from the river mouth. Dissolved oxygen content was highest directly off the mouth of the Skagit River. Surface water temperatures followed the seasonal changes in air temperature. Maximum water

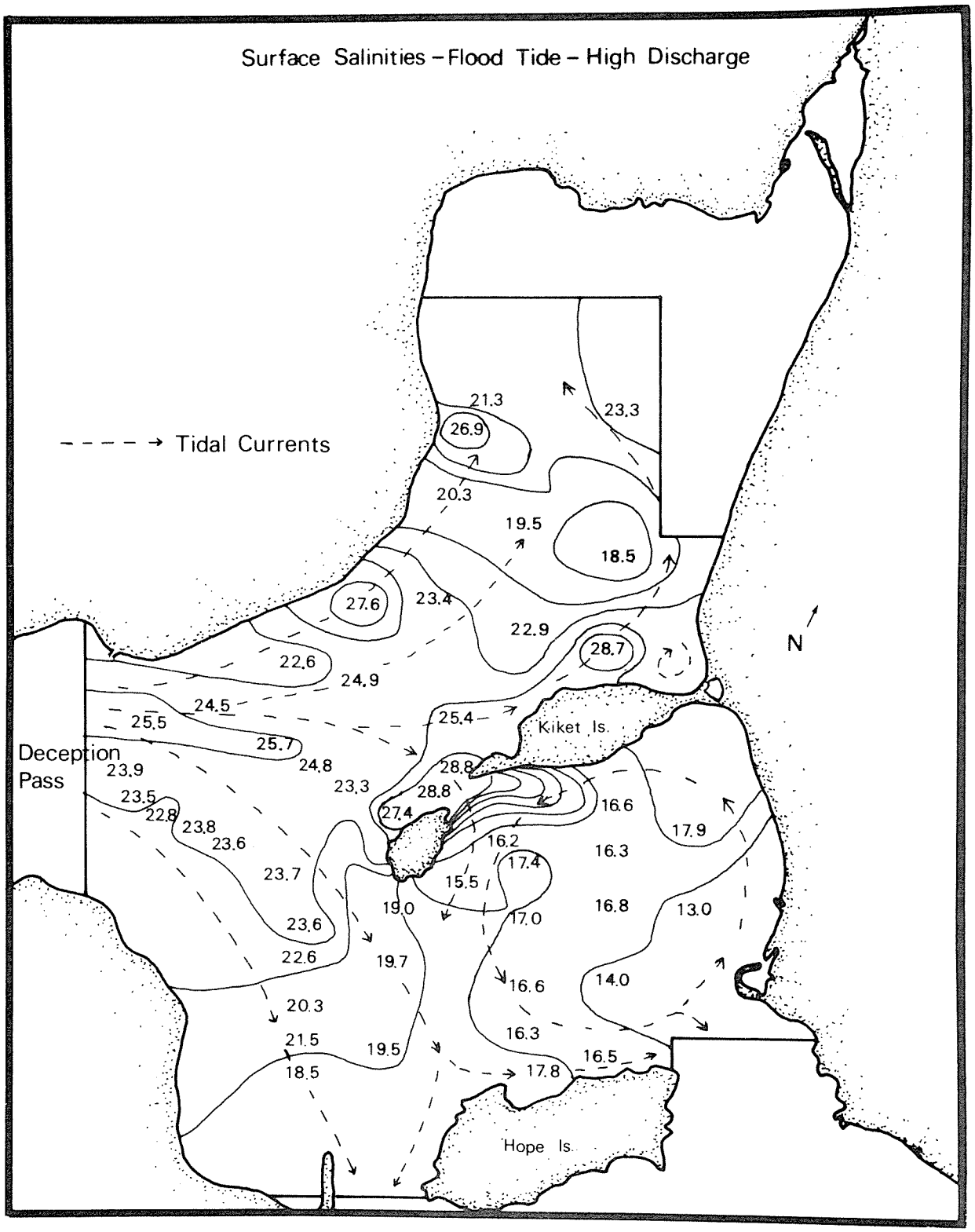

Fig. 4-14. Surface salinity contours at 2 ppt intervals during flood tide and high Skagit River discharge (67,900 cfs) in Similk and Hope Island Bays on July 14, 1972.

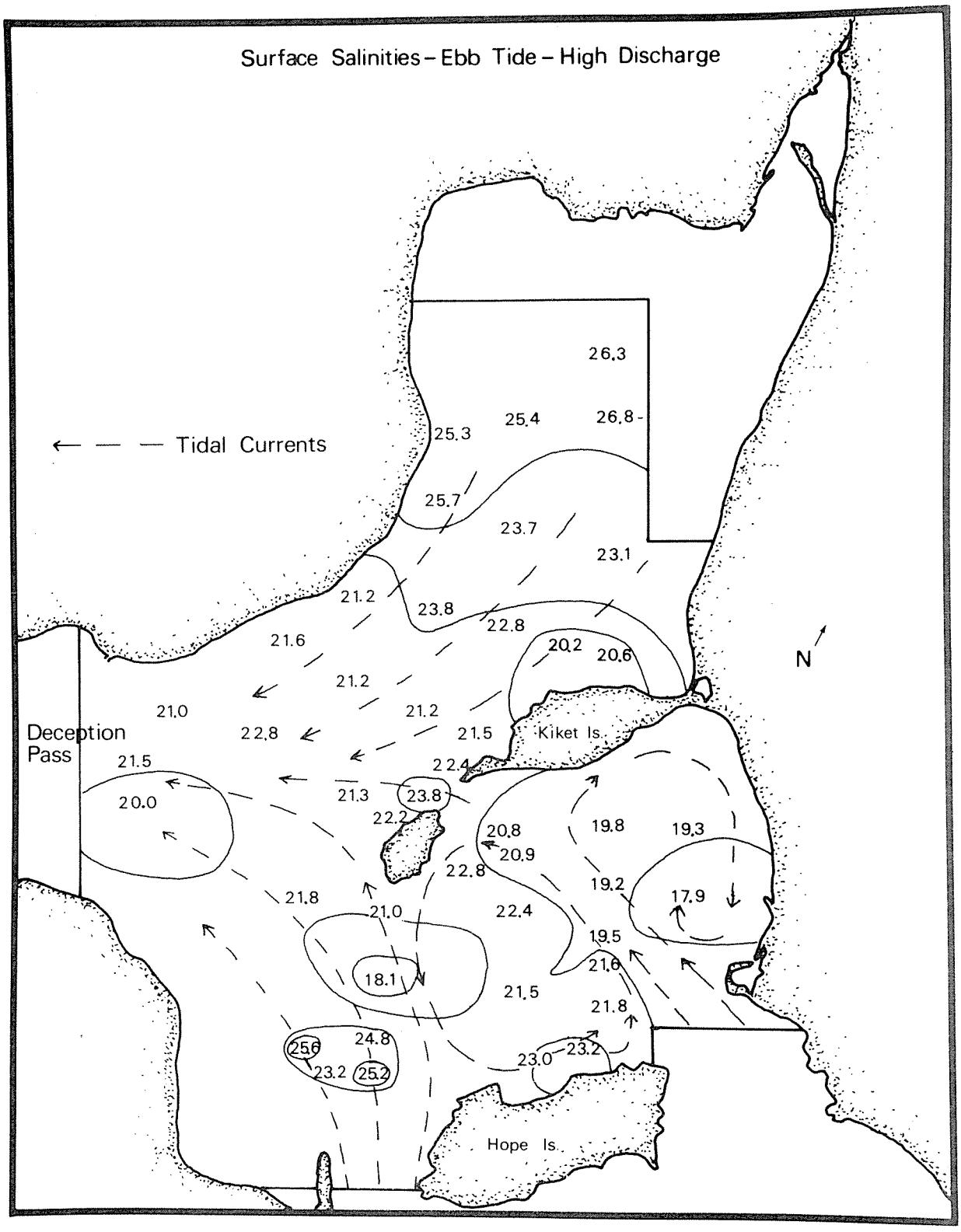

Fig. 4-15. Surface salinity contours at 2 ppt intervals during ebbtide and high Skagit River discharge (39,100 cfs) in Similk and Hope Island Bays on June 30, 1972.

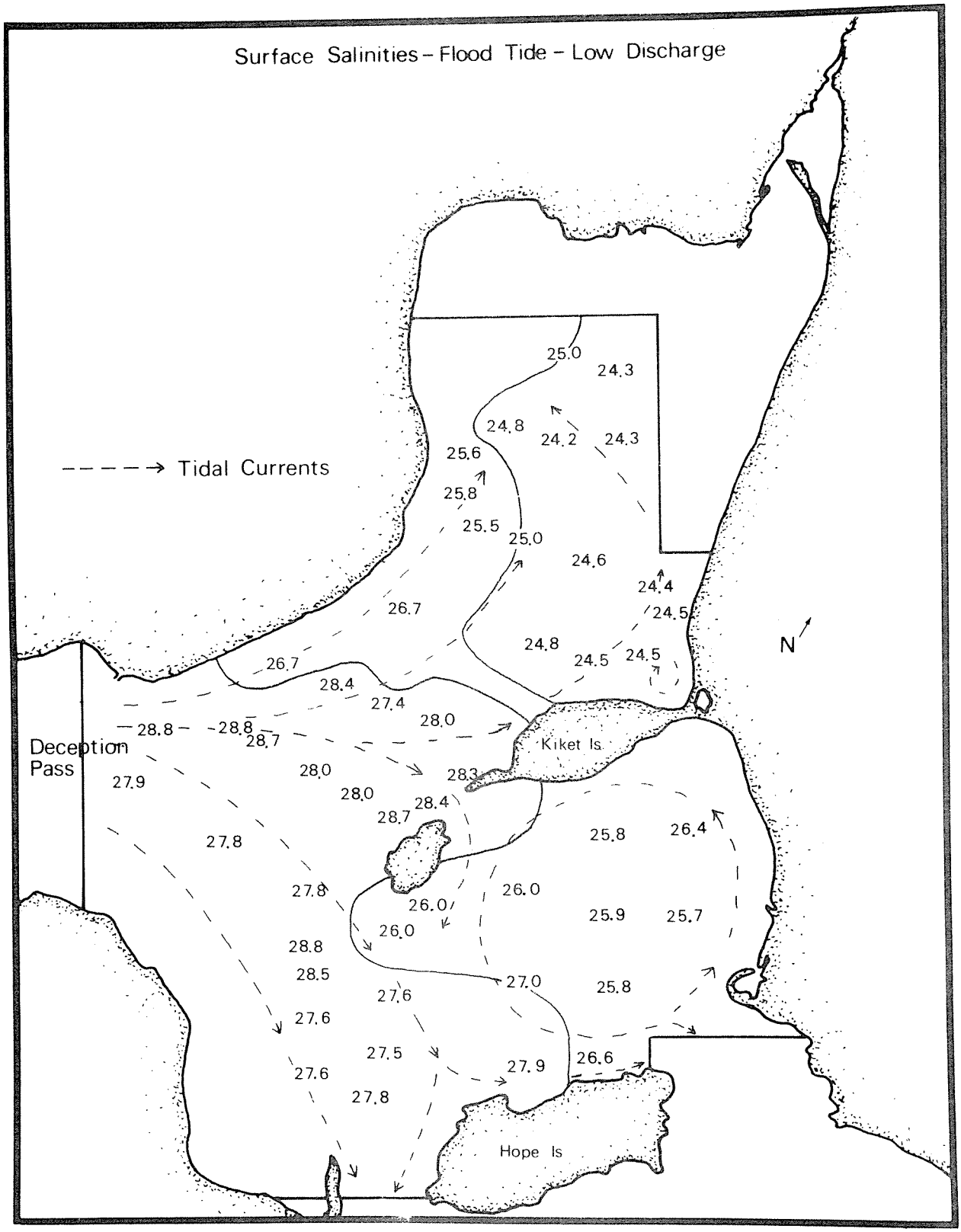

Fig. 4-16. Surface salinity contours at 2 ppt intervals during flood tide and low Skagit River discharge (17,900 cfs) in Similk and Hope Island Bays on April 28, 1972.

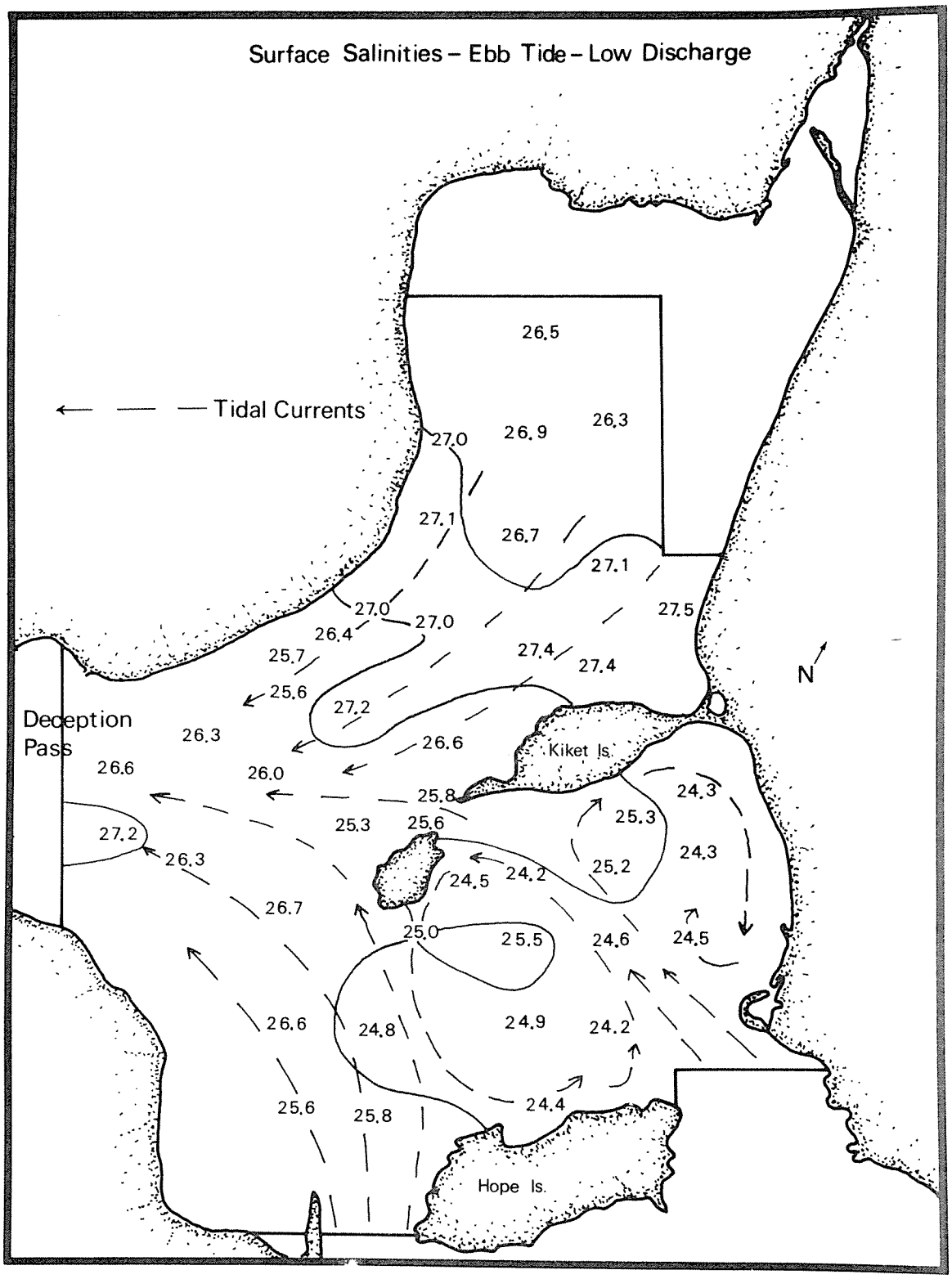

Fig. 4-17. Surface salinity contours at 2 ppt intervals during ebbtide and low Skagit River discharge (17,400 cfs) in Similk and Hope Island Bays on May 5, 1972.

temperatures recorded during July and August near the north and south shores of Kiket Island reached 17.4 C in 1970, 17.3 C in 1971, and 18.8 C in 1972. A minimum offshore temperature of 3 C was observed during January 1971 and a similar observation of 4.5 C was recorded in January 1972.

The degree of vertical stratification is also greatly influenced by the discharge from the Skagit River, with major stratification occurring during the spring period of runoff. For details of the vertical stratification of North Skagit Bay the reader is referred to Lincoln et al., 1970 and Bendiner et al., 1972.

The vertical and horizontal changes in these physical-chemical water quality parameters influence the distribution and ecology of aquatic organisms described in the remaining sections of this report. North Skagit Bay is an aquatic area with many of the physical and ecological characteristics of a well mixed estuary.

5.0 JUVENILE SALMONID MIGRATION THROUGH NORTH SKAGIT BAY

by

Q. J. Stober, S. J. Walden and D. T. Griggs

5.1 INTRODUCTION

Each year the juvenile Pacific salmon (genus *Oncorhynchus*) and steelhead trout (*Salmo gairdneri*) migrate seaward from the Skagit River system through Skagit and Similk Bays. Because of variations in early life history among these species, they differ in average size and time of migration. Young pink salmon (*O. gorbuscha*) enter the estuaries on an even year immediately after emergence from the gravel. They spend the least time in freshwater and therefore are the smallest of the migrating salmonids which average about 35 mm in length, at the time of entry into salt water. Juvenile chum salmon (*O. keta*) migrate through the estuaries every year, but are much more abundant during an odd year than in an even year. They enter sea water shortly after emergence and are only slightly larger at this time than the migrating pink salmon. Clearly, in considering ways of minimizing a potential threat to the fishery the water intake structures of the proposed power plant must be designed to minimize entrainment and impingement of juvenile migrant pink and chum salmon. Chinook salmon (*O. tshawytscha*) remain in the river or are retained in hatcheries for a few months after emergence and are about twice the size of pink and chum salmon when they enter sea water. Coho salmon (*O. kisutch*), steelhead trout, and sockeye salmon (*O. nerka*) typically spend the first year of life in freshwater and therefore attain the largest size before migration to salt water. Thus these larger species are expected to be less vulnerable to the hazards of a once-through cooling water system mainly due to their greater swimming ability. To predict the possible effects of the proposed nuclear power plant at Kiket Island on migrant juvenile salmonids, the following features were studied during periods of migration in 1970, 1971, and 1972:

1) temporal distribution by species within Skagit and Similk Bays with emphasis on migration routes;

2) spacial distribution by species, including the vertical distribution;

3) the estimated relative abundance of juvenile salmonids migrating through North Skagit Bay; and

4) size and growth of migrants in the estuary.

The primary objectives in 1972 were to obtain a second year of data on migrant pink salmon and to recover marked chinook salmon from a comprehensive tagging program by the Washington State Department of Fisheries (WSDF) from Puget Sound hatcheries. With regard to the latter, information on growth, migration routes, feeding areas, intermingling of stocks, and survival was developed, and data of assistance to the WSDF were collected. Information was obtained incidentally for several species, including chum, coho, and sockeye salmon, surf smelt (*Hypomesus pretiosus*), longfin smelt (*Spirinchus thaleichthys*), and Pacific herring (*Clupea harengus pallasi*); however, the catches of sockeye salmon were negligible. Data gathered during the 1972 field sampling are presented in detail and compared with the results of the preceding two years of study.

The study area covered North Skagit Bay, Similk Bay, and the Swinomish Channel as in 1971 (Fig. 5-1). The area of water designated II in the figure is Hope Island Bay, and Area VIII is the Swinomish Channel.

5.2 MATERIALS AND METHODS

5.2.1 Offshore Operations

Sampling was conducted by townet over a 140-day season extending from March 28 to August 15, 1972. The R.V. *Malka* was used from March 28 until June 2 and the M.V. *Steadfast*, a gill net boat refitted for townet and purse seine sampling, for the rest of the season.

There were three sampling operations; namely, continuous surface trawling, non-continuous surface trawling, and trawling at various depths. Continuous surface trawling was conducted in Similk and Hope Island Bays along the course outlined in Fig. 5-2. As in 1970 and 1971, the net was towed by two boats, and the catch was taken at 5-min intervals by a man who rode in a smaller skiff trailing over the cod end of the net.

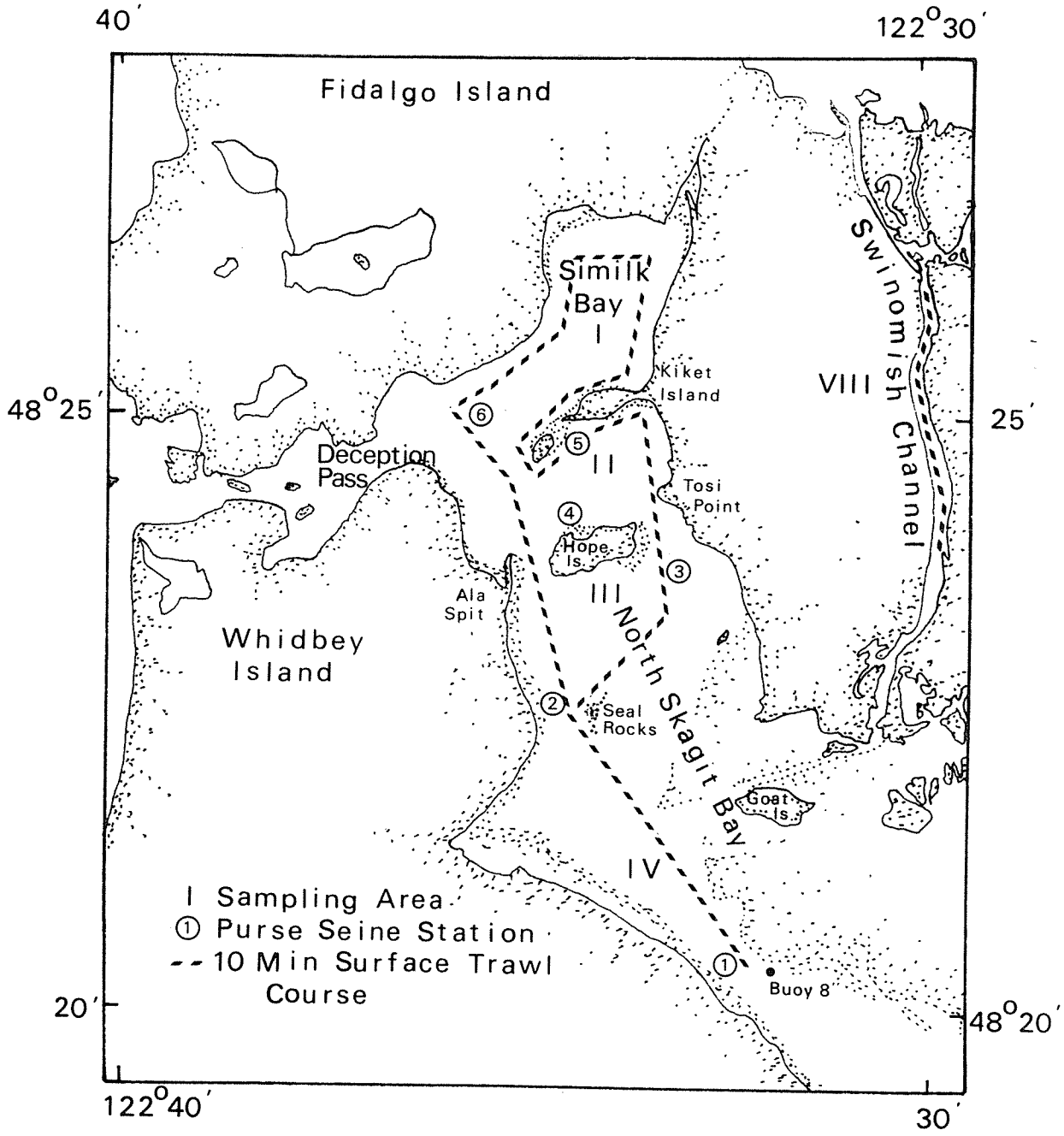

Fig. 5-1. Map of Similk Bay, North Skagit Bay, and the Swinomish Channel showing the sampling areas for the 10 min townet course and the purse seine stations, 1972.

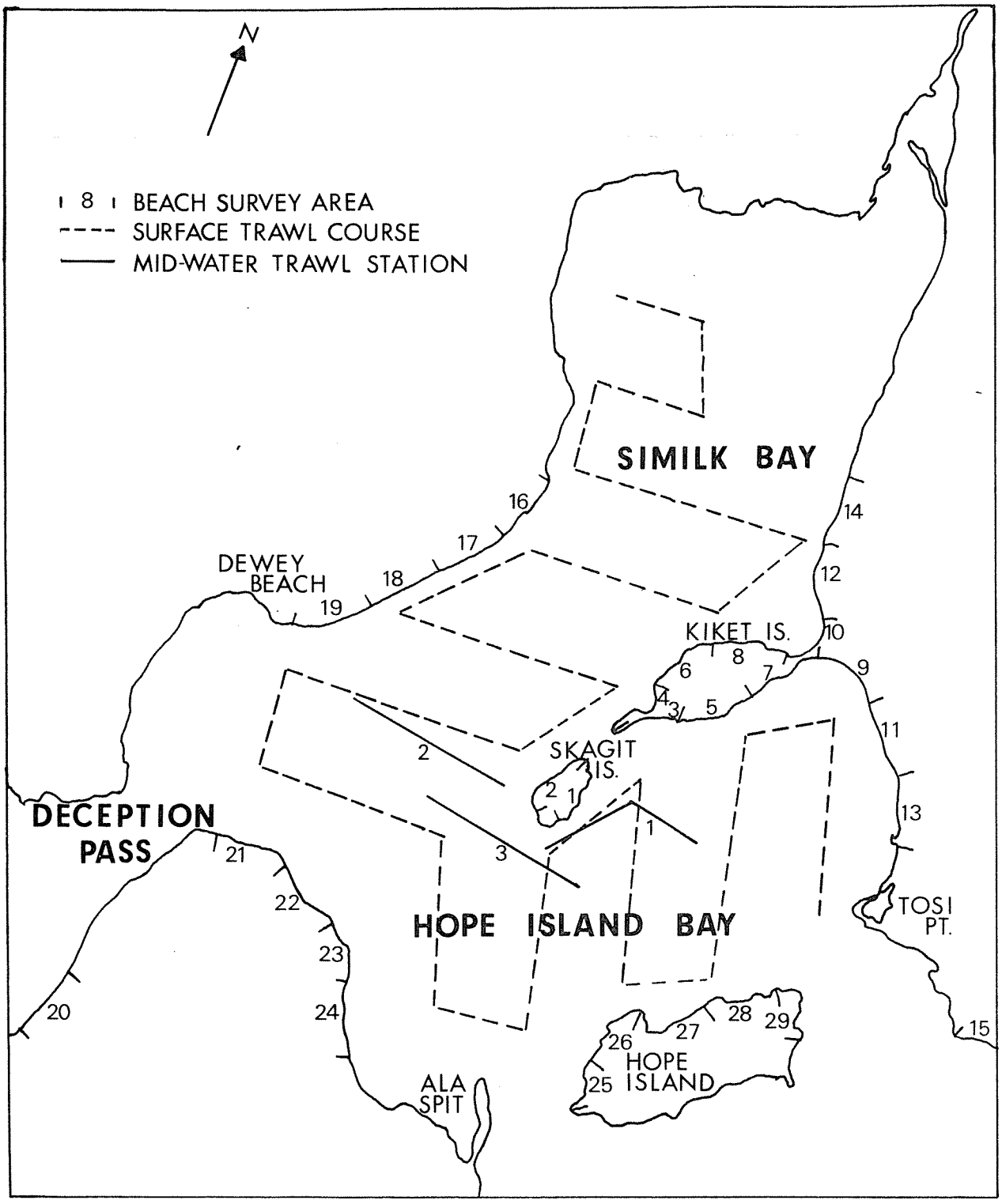

Fig. 5-2. Map of northern Skagit Bay, showing the beach survey areas, the course followed in continuous surface trawling and midwater trawl stations.

Noncontinuous surface trawls were made over Similk Bay, Skagit Bay north of No. 8 Buoy, and the Swinomish Channel (Fig. 5-1). The net was fished between two boats as in continuous surface trawling for 10 min and then hauled aboard. A fixed number of tows were performed, evenly distributed over the study area to provide uniform sampling. In 1971 the net had been fished for 10 or 15 min and hauled aboard and the vessels run for 10 or 15 min, before resetting the net.

The third operation was designed to indicate the vertical distribution of juvenile salmonids and other fish in the deeply scoured areas around Skagit Island. The three midwater stations established in 1971 (Fig. 5-2) were sampled at the surface, at 9.15 m (30 ft), and at 18.30 m (60 ft) through tows of 10-min duration each. When the weather permitted, two samples were taken during daylight and one after dark in an 18-hr period each week. The net was fished as described above for noncontinuous surface tows. Sampling was conducted at depth with otter boards. Vessel speed during towing was approximately 3 knots. As in 1971, a purse line was used initially to test whether fish were caught during raising or lowering of the net. No obvious difference in catch was observed between pursed and unpursed tows, and the practice was discontinued.

Supplemental purse seining was performed for the first time in 1972, to determine the abundance of larger fish, such as herring, smelt, steelhead trout, chinook, and coho salmon, which may avoid the tow net. An experimental purse seine was fished weekly after June 8 at six stations in Similk Bay and North Skagit Bay (Fig. 5-1). The seine was 274.2 m (900 ft) long by 9.14 m (30 ft) deep, of half-purse design with nylon web graduated from 3.175 cm (1-1/4 inches) in the lead to 1.27 cm (1/2 inches) in the bunt.

5.2.2 Inshore Operations

Beach surveys were conducted weekly from February 23 until June 7, 1972 to estimate the relative abundance, size, and timing of the juvenile pink and chum salmon along 29 0.46 km (1/4-mile) shoreline sections of Hope Island and Similk Bays (Fig. 5-2). Observers using polaroid sunglasses estimated number of fish during beach walks or shoreline cruises with a 10-ft skiff. Beach seine hauls were made periodically to provide a quantitative comparison for the visual estimates.

5.2.3 Analysis of the Data

Minimal weighted relative abundance estimates of chum and pink salmon were calculated for 1971 and 1972, respectively, from surface townet catches in Similk and Hope Island Bays. Isometric contours were charted on the basis of the relative sizes of the individual townet catches.

The procedure can best be described by the formula

$$\frac{(A_1 + A_2 + \ldots A_x)\,\bar{X}_a + (B_1 + B_2 \ldots B_x)\,\bar{X}_b + \ldots (N_1 + N_2 + \ldots N_x)\,\bar{X}_n}{dL},$$

where A, B, ...N are areas between isometric lines 0 to 10, 10 to 50, ...n to 5n; n is the number of isometric lines needed to encompass the range of catches; $\bar{X}_a$, $\bar{X}_b$ ...$\bar{X}_n$ are mean catch values within isometric lines 0 to 10, 10 to 50, ...n to 5n; d equals the distance between towing vessels in nautical miles (0.00329); and L equals the length of haul in nautical miles (0.162). The total catch values for 5- and 10-min tows were combined and the effort was adjusted by weighting of the "L" value. The value of the isometric lines increases geometrically by a factor of 5. A maximum catch efficiency is assumed, therefore estimates are minimal.

Beach survey estimates for 1970, 1971, and 1972 were obtained by multiplication of the number of miles of shoreline in Hope Island and Similk Bay 23.9 km (12.9 nautical miles) by the average number of fish per mile of shoreline. The shorelines of Hope Island and Similk Bays were measured from Tosi Point to Yokeko Point, including Skagit Island; from Hoypus Point to Ala Spit; and across the north shore of Hope Island.

5.3 RESULTS AND DISCUSSION

5.3.1 Seasonal Distribution by Species

5.3.1.1 Offshore

Large numbers of migrating juvenile pink salmon passed through North Skagit and Similk Bays during 1972. A comparison of the catch per unit of effort (CPUE) for the 5-min tows for pink salmon in 1972 with the chum salmon in 1971 and 1972 and with pink salmon in 1970 is shown in Fig. 5-3. The catch per unit of effort in 1972 was consistently greater than in 1970

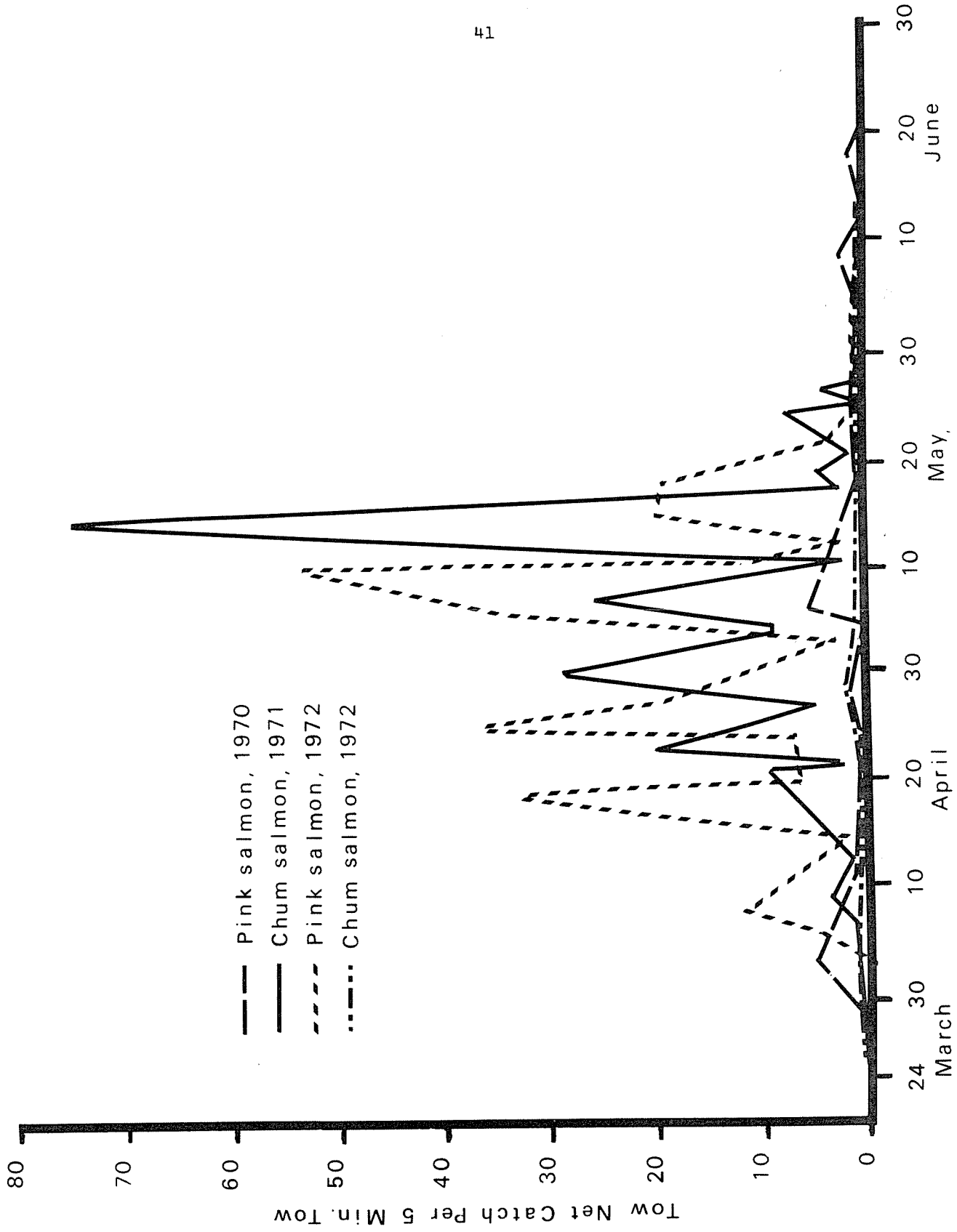

Fig. 5-3. Comparison of surface catch per 5-min tow for pink salmon in 1970, chum salmon in 1971, and pink and chum salmon in 1972.

for pink salmon; however, the sampling design and effort in 1970 were not directly comparable with that in 1971 or 1972. The sampling effort in 1970 was distributed over both North and South Skagit Bays and therefore was less than that applied solely to North Skagit Bay in 1971 and 1972. The CPUE of chum salmon in 1971 appears to compare favorably with that of pink salmon in 1972. Pink and chum salmon seem to have had a consistent temporal distribution during the three years of study, reaching maximum numbers during the first half of May. Both occurred concurrently during any one year, but during the even years pink salmon predominated and small numbers of chum salmon were present, whereas during the one odd year chum salmon predominated and pink salmon were virtually absent.

Fingerling chinook salmon first occurred in 1972 townet catches in mid-May. The Washington State Department of Fisheries released a total of 97,117 marked fingerling chinook salmon on June 15 and 66,486 similarly marked chinook on July 11 at the Skagit River Hatchery, approximately 80.45 km (50 miles) upstream. The first marked chinook salmon were taken in townet catches on June 26; indicating a minimum travel time to Skagit Bay of 11 days. The townet catch of fingerling chinook salmon taken before this date was assumed to be composed mainly of wild fish produced in the Skagit River and those taken after to be comprised of both wild and hatchery-reared fish (Fig. 5-4). There was a 3-day interval between release and recapture of marked chinook salmon in 1970; however, the release was made in the north fork of the Skagit River near the mouth. Chinook salmon present prior to June 14, 1970 were assumed to be wild.

Coho salmon first appeared in early May and increased in number rapidly as pink salmon decreased (Fig. 5-5). They were not taken in significant numbers by townet after mid-July, about a month after the pink salmon had declined to insignificant numbers. The timing of coho passage seems to have been nearly the same during all the years of the study. Analysis of the stomach contents of some fingerling chinook and coho salmon showed that they had been feeding on juvenile pink and chum salmon.

The abundance and seasonal distribution of herring and smelt in 1972 are presented in Fig. 5-6. Because of the large size of the catch, both surf smelt and longfin smelt are reported under the general category of "smelt" in this section of this report. Shortage of time did not permit separation by

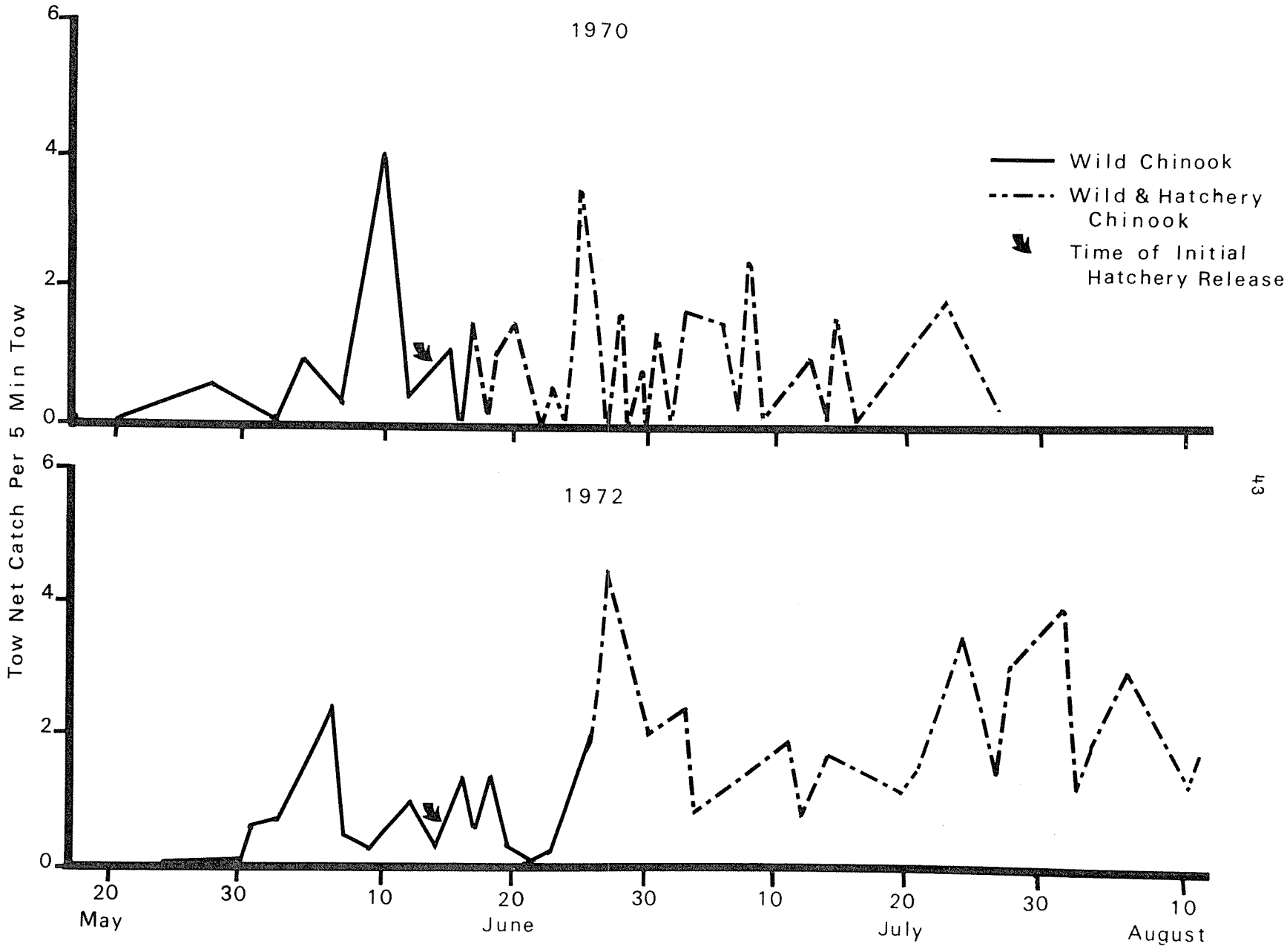

Fig. 5-4. Surface catch per 5-min tow of fingerling chinook salmon from Similk and North Skagit Bays and the Swinomish Channel in 1972.

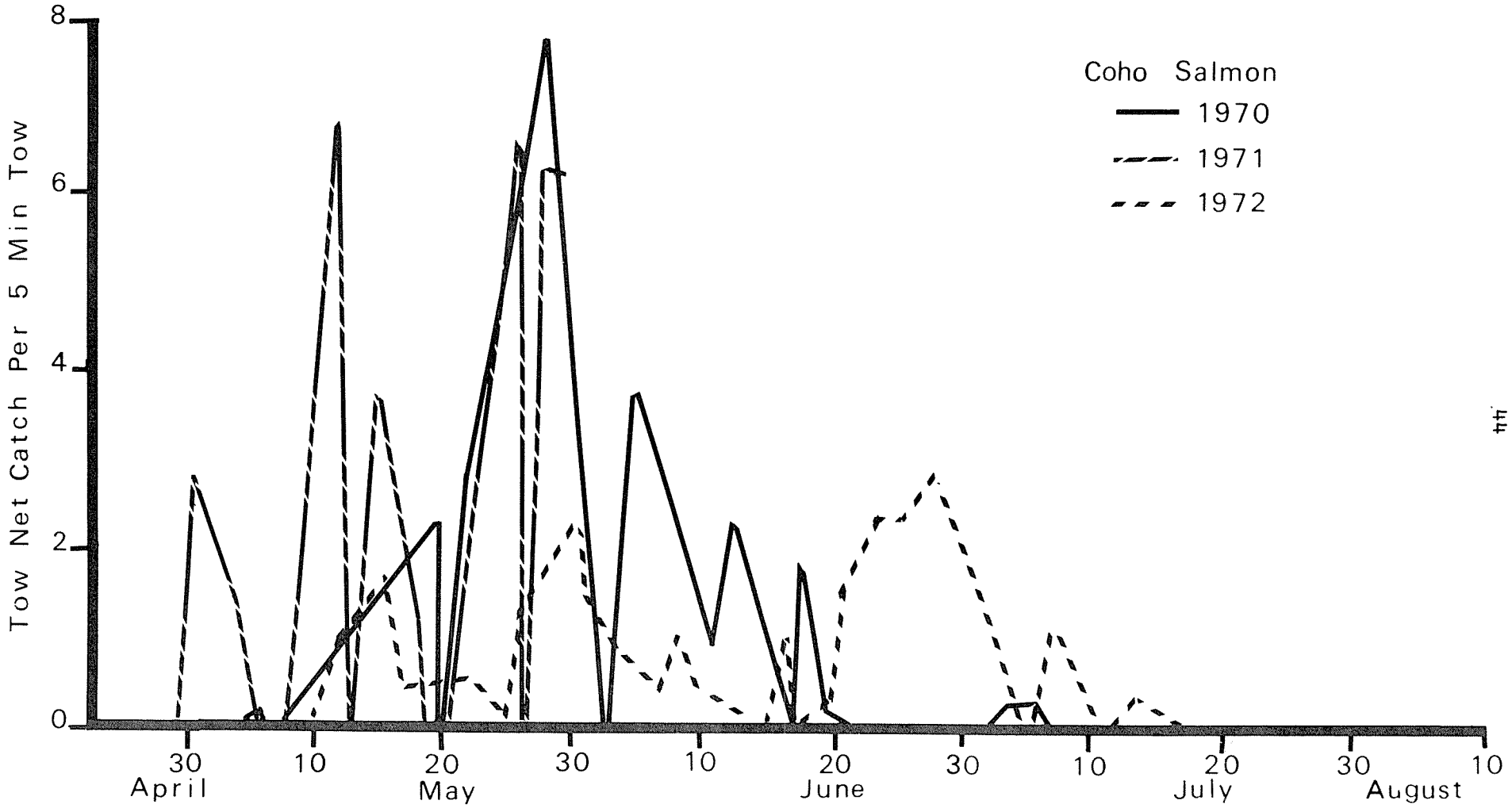

Fig. 5-5. Surface catch per 5-min tow of coho salmon from Similk and North Skagit Bays in 1970, and from Similk and North Skagit Bays and the Swinomish Channel in 1971 and 1972.

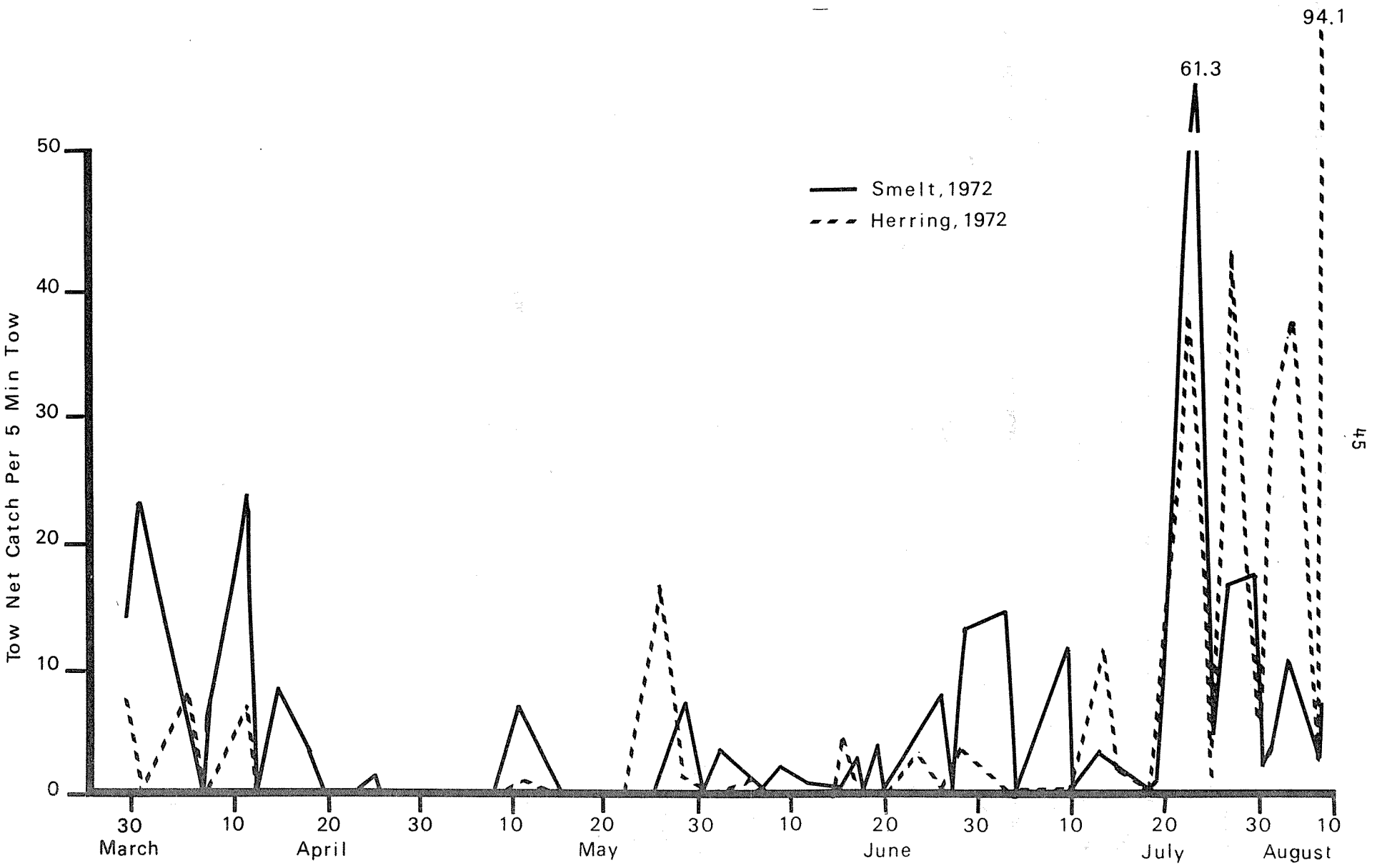

Fig. 5-6. Surface catch per 5-min tow of herring and smelt taken in Similk and North Skagit Bays and the Swinomish Channel, 1972.

species; however, surf smelt composed approximately 90 per cent of the total catch of smelt. The catch of smelt per unit of effort (5-min tow) peaked during April and again during late June through August 15. Herring were most abundant during May and again during late June through August 15.

All major salmonid migration during 1970, 1971, and 1972 occurred during some phase of a spring freshet (Water Quality, Sect. 4.0). During all three years, the abundance of pink and chum salmon peaked during early May before the peak in discharge occurred. During the 1970 and 1972 sampling seasons chinook salmon appeared just prior to the peak in discharge and increased in abundance throughout the freshet. The passage of coho salmon closely approximated that of pink and chum salmon during all three years. In 1972 herring and smelt were relatively more abundant before the freshet in April and after the freshet subsided in late July and early August. This probably stems from a preference for higher salinities by these marine species.

5.3.1.2 Inshore

The estimated weekly numbers of pink and chum salmon per 1.85 km (mile) of shoreline are compared in Fig. 5-7. The maximum abundance of juvenile pink salmon was observed during the second week in May 1972, when approximately 170,000 fish were estimated per mile of shoreline. This timing coincided with that observed in 1970, when about 2 million pink salmon were estimated per mile of shoreline. A maximum of 13,000 chum salmon was estimated per mile of shoreline in 1972, compared to a maximum of 42,000 in 1971. The general timing of migration was the same for all three years for both species, beginning in late March and extending through early June. During 1970, species differentiation was made until May 6 because dipnets were used for sampling and the fish began moving offshore; thus, a single line was used in Fig. 5-7 to represent the abundance of both species after that date.

5.3.2 Relative Abundance

Minimum weighted relative abundance estimates of the juvenile pink and chum salmon that migrated through North Skagit Bay were calculated from surface townet catches and beach surveys from Similk and Hope Island

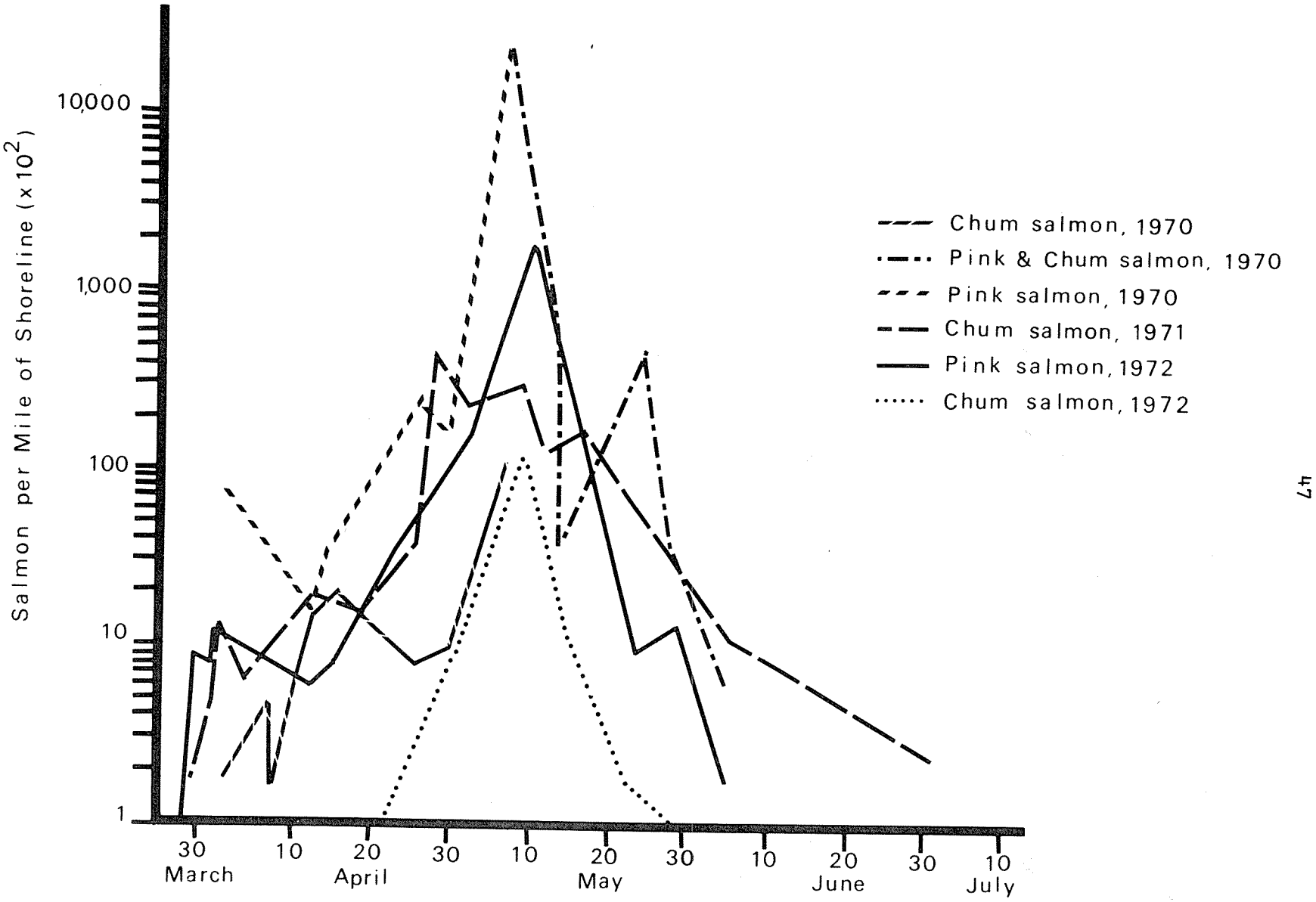

Fig. 5-7. Comparison of the relative abundance inshore of pink and chum salmon in 1970, chum salmon in 1971, and pink and chum salmon in 1972, from the beach survey estimates.

Bays in 1970, 1971, and 1972 (Table 5-1). The townet data for pink salmon in 1970 were analyzed by month because of the small sample size. The 1971 data were divided into five time periods and the 1972 data into four time periods, with a sample size of about 2,000 fish for each period. Beach survey estimates for each year were compared with the offshore abundance.

The monthly estimates of the abundance of pink salmon offshore in 1970 calculated from the townet catches were more or less consistent, averaging approximately 5,700 fish. The beach survey estimates during May exceeded 25 million fish and thus indicated a greater abundance inshore. During an observation period in May 1970 an intermittent band of fish from 5 to 25 ft wide was seen around both Kiket and Skagit Islands; arriving at an accurate estimate was virtually impossible.

The relative abundance of chum salmon in 1971 as indicated by the townet catch increased throughout April and the first half of May to slightly over 700,000 and rapidly decreased during the last half of May. Beach survey estimates showed approximately equal numbers inshore.

The relative estimates of abundance of pink salmon for the 1972 season indicated that pink salmon were about 2.5 times more abundant inshore than offshore. This distribution generally agreed with that observed in 1970; however, the data for 1970 are not strictly comparable, as has been explained. The maximum abundance was observed during May in both 1970 and 1972; but it was estimated at approximately 2.4 million fish in 1972 and approximately 25.6 million in 1970 for beach survey estimates. The intermittent band of fish surrounding both Kiket and Skagit Islands seen in 1970 was not seen in 1972. The degree of confidence with which these estimates can be regarded to reflect the strength of each year class can be determined only after a series of pink and chum salmon migrations have been studied in succession. It is clear that the greatest numbers of pinks occur inshore with lower densities offshore and tend to follow the shoreline in leaving the Bay.

5.3.3 Distribution by Area

The average offshore seasonal catch per unit effort, average inshore density and vertical distribution of pink and chinook salmon, herring, and smelt sampled in 1972 and chum salmon sampled in 1971 in Similk and Hope Island Bays are presented graphically in Figs. 5-8 to 5-12. The offshore

Table 5-1. Offshore and inshore estimates for pink salmon in 1970, chum salmon in 1971, and pink salmon in 1972 for Similk and Hope Island Bays combined

Species and date	Offshore	Inshore	Total
Pink salmon, 1970			
April	6,742	1,099,622	1,106,364
May	4,622	25,689,924	25,694,546
June	5,967	109,805	115,772
Total	17,331	26,899,351	26,916,682
Chum salmon, 1971			
3/24 to 4/28	114,900	13,630	128,530
4/30 to 5/6	220,100	487,878	707,978
5/7 to 5/13	152,635	186,878	339,513
5/14	710,040	206,488	916,528
5/18 to 5/28	47,116	113,894	161,010
Total	1,244,791	1,008,768	2,253,559
Pink salmon, 1972			
3/28 to 4/14	343,357	31,058	374,415
4/18 to 4/28	335,385	53,392	388,777
5/2 to 5/9	348,423	2,391,806	2,740,229
5/12 to 6/9	105,567	344,533	450,100
Total	1,132,732	2,820,789	3,953,521

Pink Salmon, 1972

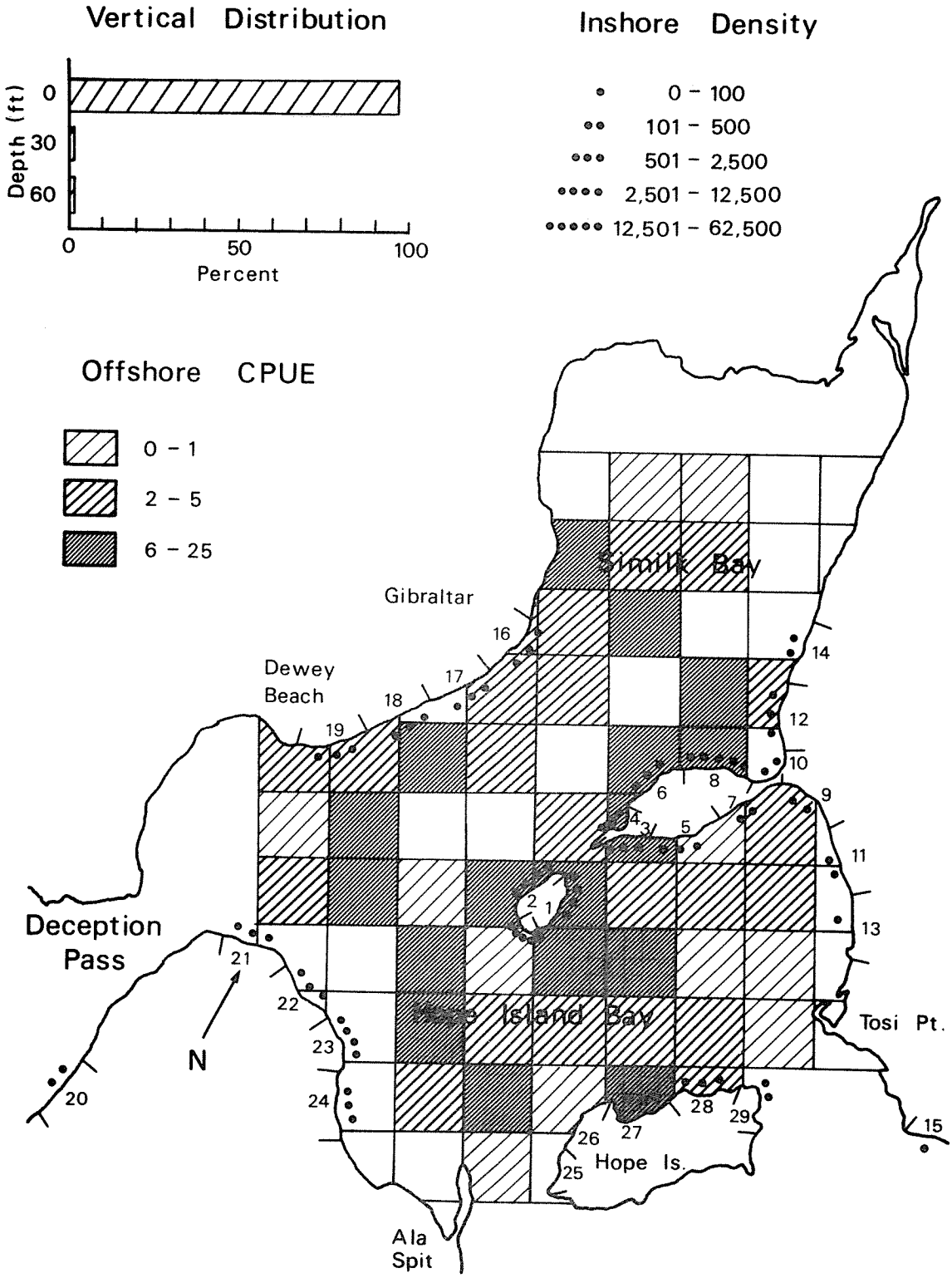

Fig. 5-8. Average offshore seasonal catch per unit effort, average inshore density, and vertical distribution of pink salmon sampled in 1972 in Similk and Hope Island Bays.

Chinook Salmon, 1972

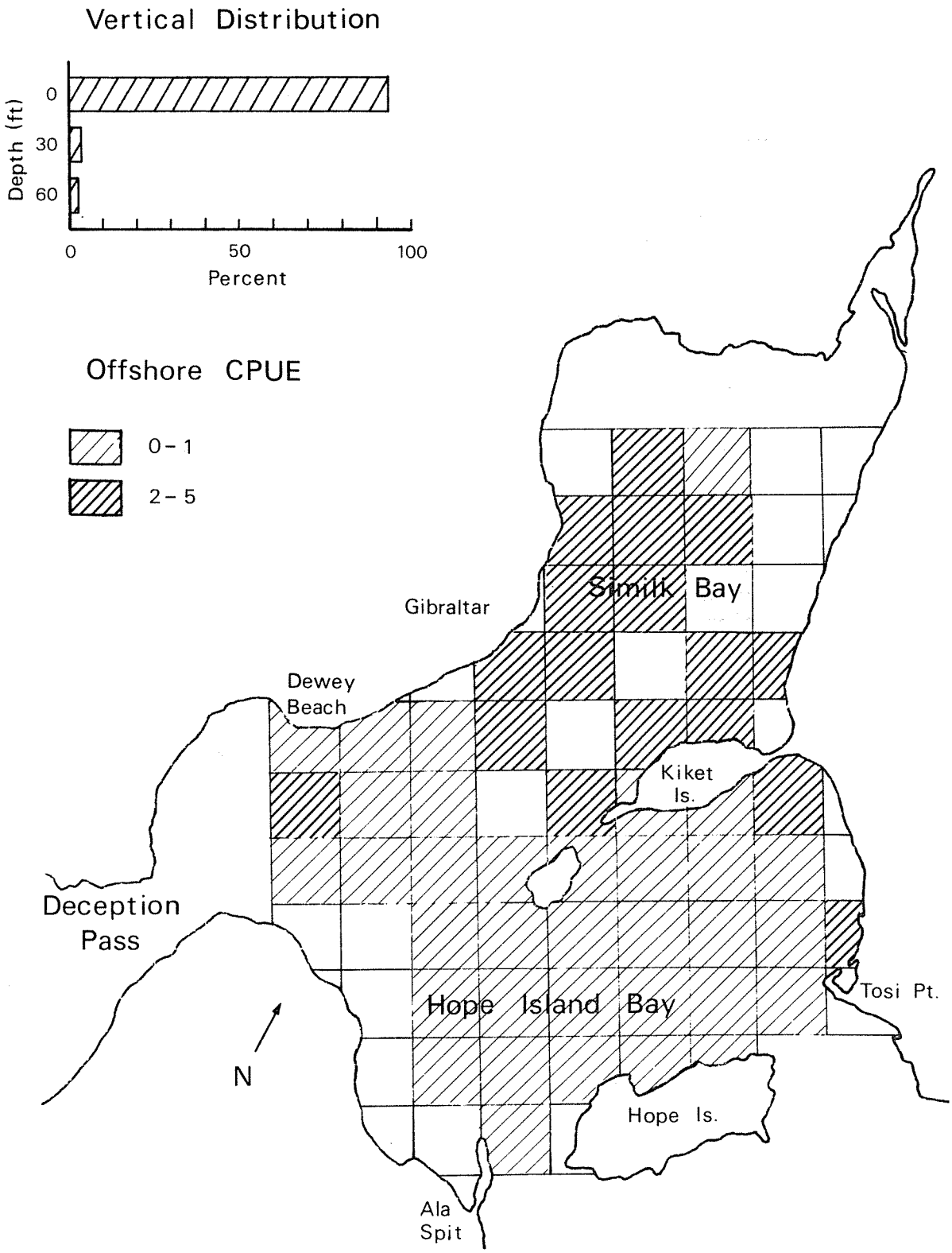

Fig. 5-9. Average offshore seasonal catch per unit effort, and vertical distribution of chinook salmon sampled in 1972 in Similk and Hope Island Bays.

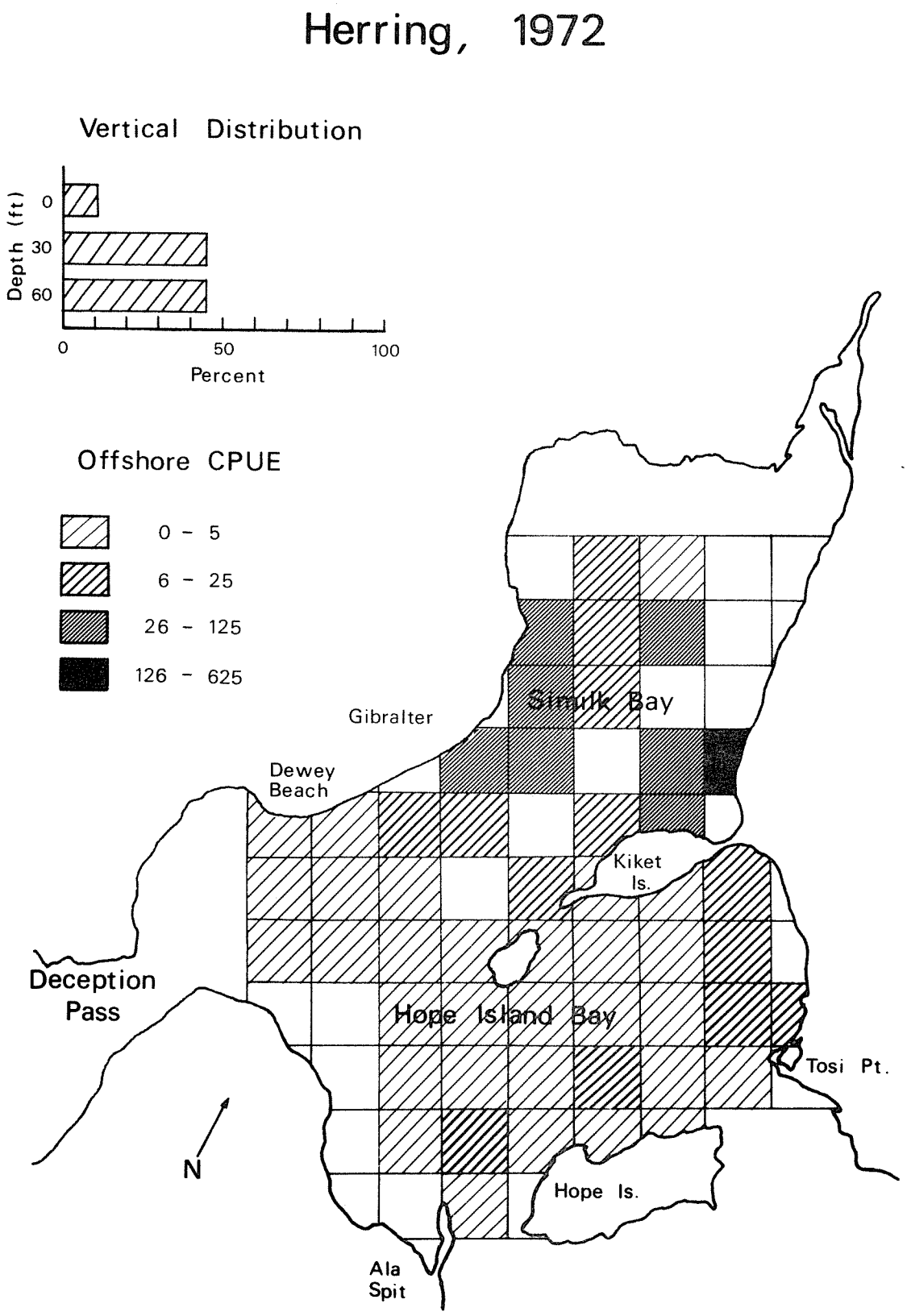

Fig. 5-10. Average offshore seasonal catch per unit effort and vertical distribution of Pacific herring sampled in 1972 in Similk and Hope Island Bays.

Smelt, 1972

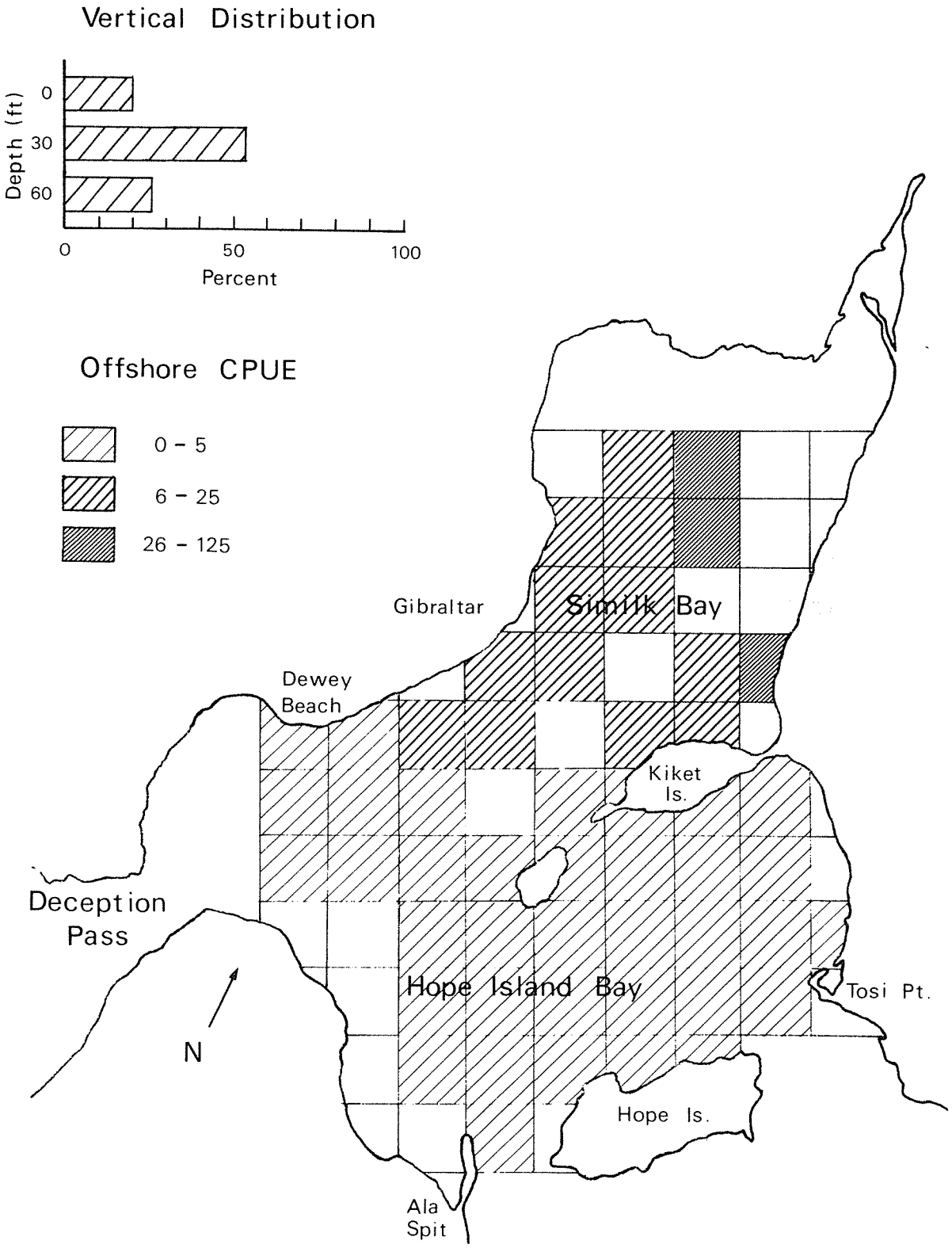

Fig. 5-11. Average offshore seasonal catch per unit effort and vertical distribution of smelt sampled in 1972 in Similk and Hope Island Bays.

Chum Salmon, 1971

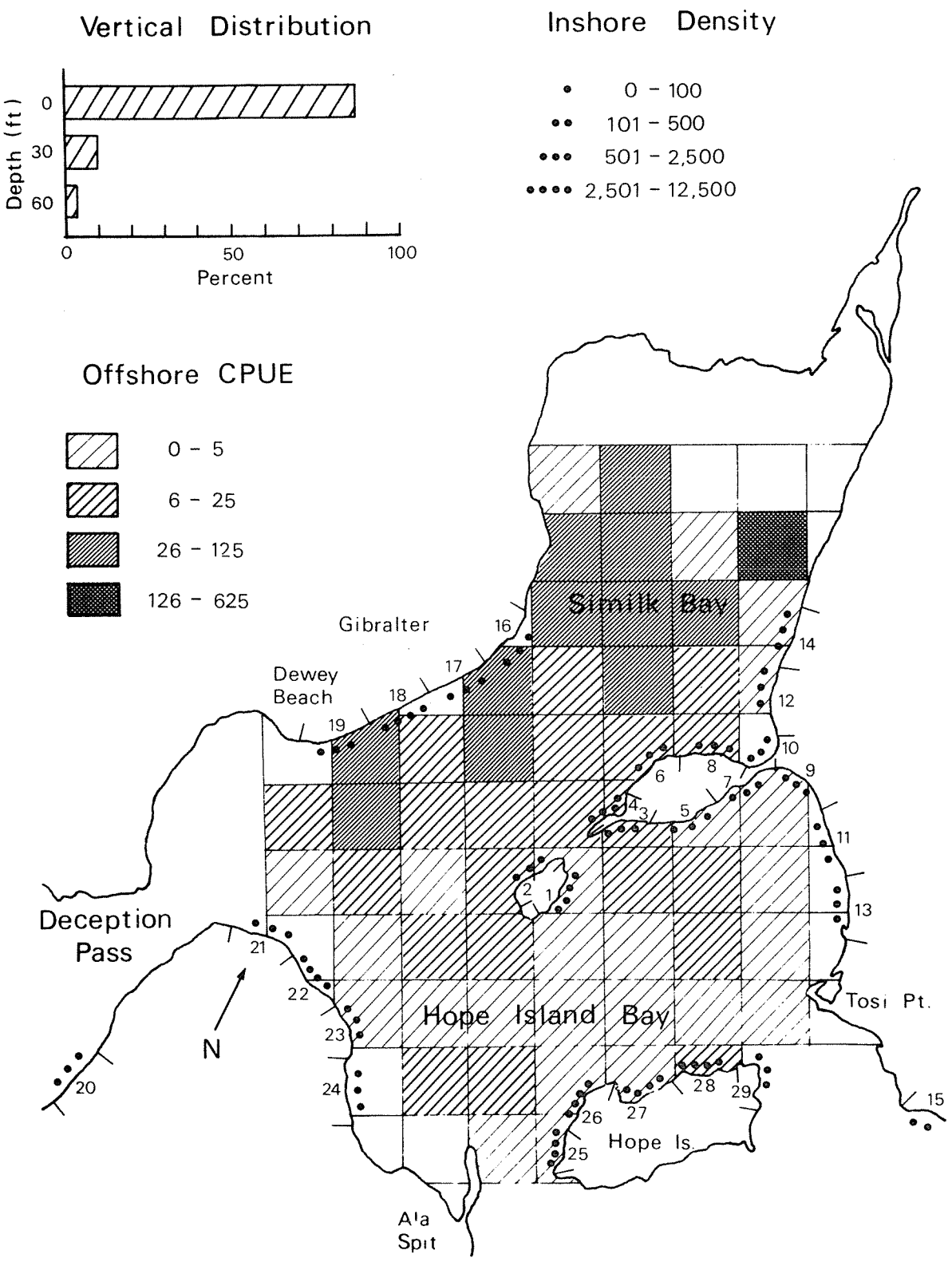

Fig. 5-12. Average offshore seasonal catch per unit effort, average inshore density, and vertical distribution of chum salmon sampled in 1971 in Similk and Hope Island Bays.

surface distribution is expressed as the average seasonal townet CPUE for 5-min tows per 0.46 km^2 (1/4-square-nautical mile) grid area, and the inshore seasonal distribution and abundance of pink salmon (1972) and chum salmon (1971) are expressed as the average number of fish per observation in each of 29 0.46 km (1/4-nautical mile) beach survey areas.

In 1972 pink salmon were found highly concentrated inshore around Skagit Island and along the north shores of Kiket and Hope Islands (Fig. 5-8), and schooled in slack water along the shore-water interface where the tidal current velocities were reduced. The offshore density was approximately equal in each Bay area. The blank grid areas in Similk Bay in Fig. 5-8 resulted from a lack of samples due to the configuration of the surface trawling course. The vertical distribution of pink salmon indicated 96.7 per cent occurred within 10 ft of the surface, 1.4 per cent at 30 ft, and 1.9 per cent at 60 ft.

Chinook salmon in 1972 consistently occurred in greatest abundance in Similk Bay (Fig. 5-9). The vertical distribution indicated 93.8 per cent occurred at the surface, 4.4 per cent at 30 ft, and 1.8 per cent at 60 ft. Herring and smelt both occurred in greatest abundance in Similk Bay (Figs. 5-10, 5-11, respectively). About 10.7 per cent of the herring were caught at the surface, 44.5 per cent at 30 ft, and 44.8 per cent at 60 ft. Of the smelt 54.5 per cent were found at 30 ft, 19.3 per cent at the surface, and 26.2 per cent at 60 ft.

Chum salmon sampled in 1971 were more evenly distributed between inshore and offshore areas (Fig. 5-12). They were observed in large numbers inshore along the peripheries of Similk and Hope Island Bays, but were found in greater concentrations offshore in Similk Bay than in Hope Island Bay. The vertical distribution of chum salmon indicated 87 per cent occurred near the surface, 10 per cent at 30 ft, and 3 per cent at 60 ft.

5.3.4 Distribution of Total Townet Catch by Area and Species

The total townet catch of salmonids for all areas and the per cent of the total catch by area are presented for the 1970, 1971, and 1972 sampling seasons in Table 5-2. Pink salmon were the most abundant species in 1970 and 1972, while chum salmon were the most abundant in 1971.

Table 5-2. Per cent salmonid townet catch by sampling area during the 1970, 1971, and 1972 seasons

	Area							Total number of tows
	I	II	III	IV	V & VI	VII	VIII	
Effort								
1970								
5 min tows	21	17	14	10	16	22	--	2,756
1971								
5 min tows	59	41	--	--	--	--	--	428
10 min tows	29	41	15	6	--	--	9	307
15 min tows	30	70	--	--	--	--	--	110
1972								
5 min tows	59	41	--	--	--	--	--	964
10 min tows	31	43	15	4	--	--	7	823
Species								Total catch
Pink salmon								
1970	10	11	11	9	41	18	--	3,477
1971	67	17	--	16	--	--	--	6
1972	45	40	4	8	--	--	3	14,363
Chum salmon								
1970	10	10	16	8	42	14	--	676
1971	66	26	1	3	--	--	4	10,412
1972	47	34	6	8	--	--	5	547
Sockeye salmon								
1970	32	62	2	3	--	1	--	71
1971	100	--	--	--	--	--	--	2
1972	--	--	--	--	--	--	--	0
Coho								
1970	53	19	15	5	5	3	--	1,317
1971	75	15	2	5	--	--	3	1,537
1972	60	26	6	3	--	--	5	1,414
Fingerling chinook salmon								
1970	29	10	19	8	25	9	--	1,879
1971	88	9	2	1	--	--	--	67
1972	64	18	5	3	--	--	10	2,354
Yearling chinook salmon								
1970	66	10	6	3	5	10	--	300
1971	82	9	--	9	--	--	--	22
1972	33	19	9.5	9.5	--	--	29	21
Resident chinook (blackmouth) salmon								
1970	--	--	--	--	--	--	--	--
1971	--	100	--	--	--	--	--	5
1972	--	100	--	--	--	--	--	2
Steelhead trout								
1970	39	24	11	11	6	9	--	87
1971	48	43	2	7	--	--	--	44
1972	31	14	41	14	--	--	--	36
Cutthroat trout								
1970	5	14	5	--	19	57	--	21
1971	--	--	--	--	--	--	--	0
1972	100	--	--	--	--	--	--	1
TOTAL CATCH								
1970								7,828
1971								12,095
1972								18,738

The greatest percentage of pink and chum salmon were caught in southern Skagit Bay during 1970 and in Similk Bay in 1971 and 1972. Southern Skagit Bay was not sampled after 1970. Sockeye salmon were taken in greatest numbers in Hope Island Bay in 1970 and only two were taken in Similk Bay in 1971. No sockeye salmon were taken in 1972. The greatest percentage of coho, fingerling chinook, yearling chinook salmon, and steelhead trout occurred in Similk Bay for all three years. Cutthroat trout were taken in greatest numbers in southern Skagit Bay during 1970, none were taken in 1971, and one was taken in Similk Bay during 1972. A total of seven resident chinook salmon (blackmouth) were taken in Hope Island Bay during 1971 and 1972.

The total townet catch of resident species for all areas and the per cent of the total catch by area is presented for the 1970, 1971, and 1972 sampling seasons in Table 5-3. Pacific herring was the most abundant resident species in 1970, larval fishes were most abundant in 1971 and consisted primarily of herring, surf smelt and sand lance (*Ammodytes hexapterus*). Threespine stickleback (*Gasterosteus aculeatus*) were most abundant during the 1972 season. The greatest percentage of herring and smelt occurred in Similk Bay during all three years. More sand lance occurred in the Swinomish Channel during the 1971 and 1972 seasons. The Swinomish Channel was not sampled in 1970. The threespine stickleback, Northern anchovy (*Engraulis mordax*), and Pacific lamprey (*Entosphenus tridentatus*) were most common in Similk Bay. Larval fishes occurred in greatest numbers in Hope Island Bay in 1970, Similk Bay in 1971, and the Swinomish Channel in 1972.

Plainfin midshipman (*Porichthys notatus*) were most abundant in Hope Island Bay in 1970, a total of six were taken in Hope Island and Similk Bays in 1971, and only a single individual was taken in Hope Island Bay in 1972. Surfperch (Embiotocidae) were taken in greater numbers in southern Skagit Bay in 1970, and Hope Island Bay in 1971 and 1972. A list of miscellaneous species taken in 1971 and 1972 is given in Table 5-4. All miscellaneous fish were pooled together under the general category of "Miscellany" in 1970.

The results of sampling by townet in the Swinomish Channel during 1972 are shown in Table 5-5. The sampling area was the same as that during 1971 and extended approximately 5.6 km (3 nautical miles) from LaConner, Washington, to the Highway 536 bridge. Wide ranges in catch per unit of effort were

Table 5-3. Per cent by sampling area of resident pelagic species caught by townet during the 1970, 1971, and 1972 seasons

	Area							Total number of catch
	I	II	III	IV	V & VI	VII	VIII	
Species								
Pacific herring								
1970	32	6	7	2	20	33	--	56,344
1971	50	48	0	1	--	--	1	3,052
1972	71	17	3	2	--	--	7	15,495
Smelt								
1970	37	6	8	7	18	24	--	28,752
1971	53	17	0	0	--	--	30	1,966
1972	63	15	5	4	--	--	13	13,195
Pacific sand lance								
1970	57	5	17	1	2	18	--	15,138
1971	0.5	0.5	0	0	--	--	99	3,369
1972	4	1	6	2	--	--	87	8,989
Threespine stickleback								
1970	84	10	6	--	--	--	--	16,493
1971	90	9	1	0	--	--	0	3,586
1972	74	20	1	0	--	--	5	15,817
Northern anchovy								
1970	74	2	--	--	--	24	--	7,574
1971	62	38	0	0	--	--	0	21
1972	58	42	0	0	--	--	0	104
Larval fish								
1970	35	40	14	5	1	5	--	6,248
1971	81	4	0	0	--	--	15	6,584
1972	35	8	3	2	--	--	52	12,345
Plainfin midshipman								
1970	24	44	23	5	2	2	--	484
1971	50	50	0	0	--	--	0	6
1972	0	100	0	0	--	--	0	1
Surf perch								
1970	22	3	22	2	22	29	--	350
1971	28	72	0	0	--	--	0	89
1972	12	79	2	0	--	--	7	42
Pacific lamprey								
1970	12	4	7	6	31	40	--	380
1971	75	0	25	0	--	--	0	4
1972	57	39	2	0	--	--	2	51
Miscellaneous								
1970	16	14	22	12	13	23	--	834
1971	38	61	0	1	--	--	0	380
1972	31	61	6	0	--	--	2	1,107
Total catch								
1970								132,597
1971								19,057
1972								67,146

Table 5-4. A list of miscellaneous resident species that occurred in the townet catch during the 1971 and 1972 seasons

Common name	Scientific name	Number 1971	Number 1972
Spiny dogfish	*Squalus acanthias*	30	53
Pacific tomcod	*Microgadus proximus*	19	63
Pacific cod	*Gadus macrocephalus*	1	0
Pipefish	*Syngnathus griseolineatus*	1	6
Snake prickleback	*Lumpenus sagitta*	135	---
Gunnels, various	Pholidae	---	27
Kelp greenling	*Hexagrammos decagrammus*	47	0
Sculpins, various	Cottidae	112	935
Sturgeon poacher	*Agonus acipenserinus*	4	8
Righteye flounders, various	Pleuronectidae	---	2
Starry flounder	*Platichthys stellatus*	16	---
English sole	*Parophrys vetulus*	12	11
Pacific sanddab	*Citharichthys sordidus*	3	2
	TOTAL CATCH	380	1,107

Table 5-5. Surface distribution of salmon, herring, smelt, and Pacific sand lance taken by townet in the Swinomish Channel during the 1972 sampling season

Grid area	Location in channel	Number of 10-min tows	Pink salmon		Chum salmon		Chinook salmon		Coho salmon		Herring		Smelt		Sand lance	
			catch	(C/T)	catch	(C/T)	catch	(C/T)	catch	(C/T)	catch	(C/T)	catch	(C/T)	catch	(C/T)
195	North	1	0	(0.00)	0	(0.00)	1	(1.00)	10	(10.00)	0	(0.00)	0	(0.00)	1	(1.00)
194		0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
193		1	70	(70.00)	0	(0.00)	0	(0.00)	0	(0.00)	1	(1.00)	2	(2.00)	5	(5.00)
192		16	15	(0.94)	5	(0.31)	119	(7.43)	20	(1.25)	126	(7.88)	336	(21.00)	2530	(158.12)
191		1	1	(1.00)	0	(0.00)	0	(0.00)	0	(0.00)	0	(0.00)	2	(2.00)	0	(0.00)
190		1	1	(1.00)	0	(0.00)	0	(0.00)	0	(0.00)	0	(0.00)	2	(2.00)	0	(0.00)
189		0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
188	Middle	2	2	(1.00)	0	(0.00)	0	(0.00)	4	(2.00)	0	(0.00)	0	(0.00)	6	(3.00)
187		17	31	(1.82)	3	(0.18)	65	(3.82)	9	(0.53)	553	(32.53)	486	(28.59)	2318	(136.65)
186		1	11	(11.00)	1	(1.00)	0	(0.00)	0	(0.00)	2	(2.00)	2	(2.00)	50	(50.00)
185		2	7	(3.50)	2	(1.00)	5	(2.50)	2	(1.00)	0	(0.00)	30	(15.00)	0	(0.00)
184		2	35	(17.50)	0	(0.00)	0	(0.00)	0	(0.00)	0	(0.00)	2	(1.00)	13	(6.50)
183		4	9	(2.25)	0	(0.00)	1	(0.25)	0	(0.00)	50	(12.50)	84	(21.00)	17	(4.25)
182	South	17	238	(14.00)	17	(1.00)	34	(2.00)	23	(1.35)	278	(16.35)	793	(46.65)	2850	(167.65)
Total		65	420	(6.50)	28	(0.43)	225	(3.50)	68	(1.05)	1010	(15.53)	1739	(26.75)	7790	(119.85)

observed for all species. The greatest catch of pink and chum salmon was obtained near the southern end of the channel, whereas that of fingerling chinook salmon was taken near the northern end. Herring were more abundant midway along the channel than elsewhere, and coho salmon, smelt, and sand lance were taken throughout the channel. Studies in 1971 of chum and coho salmon showed that more fish were taken at the northern end of the channel per 10-min tow. Pacific sand lance were the most abundant fish followed by larval fish, smelt, herring, threespine stickleback, pink salmon, chinook salmon, and fish of other species in order of decreasing abundance.

It should be noted here that effort was not uniformly distributed over all areas in all cases for the total catches expressed in Tables 5-2 and 5-3. More tows were made in Similk and Hope Island Bays, the most probable site of the cooling water intake structure, than in other areas and both 5- and 10-min tows were made.

The total purse seine catch of salmonids, herring, and smelt for 1972 is presented in Table 5-6. The purse seine was most effective in sampling herring and smelt with 245 and 46 individuals per set, respectively. A low catch per unit effort was seen for all salmonids, with only 2.8 chinooks per set.

Purse seine fishing was less effective in terms of quantity than townet fishing in this study for several reasons. The length of time required to make a set and the large mesh size in the bunt allowed many fish to escape. Purse seine operations were limited to areas greater than 5 fm in depth because of the depth of the seine, and sets could not be made in areas of great tidal flux, greatly restricting the areas which could be effectively sampled with this gear.

5.3.5 Length-Frequency Distribution and Growth for all Sampling Areas

An analysis of the length frequencies of pink, chum, chinook, and coho salmon, herring, and smelt captured by townet and by purse seine are presented in Tables 5-7 and 5-8, respectively. The mean total lengths by week for pink, chum, and coho salmon taken by townet in 1972 indicate constant recruitment throughout the sampling period and compare favorably with similar data obtained in 1970 and 1971. The average weekly sizes of pink and chum salmon appear to have doubled in June and indicate

Table 5-6. Purse seine catch by area (20-min set) of salmon, herring, and smelt taken in North Skagit Bay from June 8 to August 4, 1972

Area	Pink salmon			Chum salmon			Chinook salmon			Coho salmon			Smelt			Herring		
	Number of sets	Catch	CPUE	Number of sets	Catch	CPUE	Number of sets	Catch	CPUE	Number of sets	Catch	CPUE	Number of sets	Catch	CPUE	Number of sets	Catch	CPUE
I	11	9	(0.82)	11	0	(0.00)	11	36	(3.27)	11	11	(1.0)	11	140	(12.7)	11	2332	(212.0)
II	17	0	(0.00)	17	0	(0.00)	17	25	(1.47)	17	11	(0.65)	10	682	(68.2)	10	2657	(265.7)
III	18	0	(0.00)	18	0	(0.00)	18	68	(3.80)	18	0	(0.00)	11	514	(46.7)	11	2695	(245.0)
IV	8	0	(0.00)	8	0	(0.00)	8	21	(2.63)	8	0	(0.00)	15	843	(56.2)	15	3835	(255.4)
Species total	54	9	(0.17)	54	0	(0.00)	54	150	(2.80)	54	22	(0.41)	47	2179	(46.36)	47	11519	(245.09)

Table 5-7. Weekly mean total lengths (in mm) of salmon, herring, and smelt taken by townet in North Skagit Bay and the Swinomish Channel from March 28 to August 15, 1972

Month	Week No.	Pink salmon			Chum salmon			Chinook salmon			Coho salmon			Smelt			Herring		
		$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD
March	4	34	44	1.5	37	2	1.4	--	--	--	--	--	--	135	23	9.4	96.5	78	12.4
April	1	35	50	1.8	46.2	50	3.6	--	--	--	--	--	--	130.1	50	5.33	108.1	50	15.8
April	2	35.8	52	1.8	40.1	14	1.5	--	--	--	--	--	--	93.8	50	36.5	124.1	50	21.1
April	3	39.1	50	4.2	44.5	37	4.2	--	--	--	--	--	--	--	--	--	--	--	--
May	1	37.25	89	1.9	41.7	32	3.7	--	--	--	--	--	--	--	--	--	--	--	--
May	2	35.3	49	1.5	36.6	5	1.5	--	--	--	--	--	--	--	--	--	--	--	--
May	3	40.4	50	4.9	43.0	32	3.0	--	--	--	--	--	--	--	--	--	--	--	--
June	3	--	--	--	--	--	--	84.0	44	22.0	107.2	9	11.4	95.9	45	18.4	157.3	10	41.4
June	4	74.2	25	24.0	77.2	23	16.3	96.2	104	12.1	94.9	147	17.4	91.6	32	7.7	137.6	56	10.1
June	5	84.3	7	12.0	26.4	8	6.9	85.4	156	12.5	83.9	133	9.6	87.9	35	12.2	133.4	12	43.7
July	1	--	--	--	--	--	--	89.5	105	12.7	85.0	9	13.0	102.0	52	18.0	97.0	31	50.1
July	2	--	--	--	--	--	--	91.9	87	14.5	92.0	6	1.9	101.5	39	14.0	146.0	21	37.7
July	3	--	--	--	--	--	--	94.0	75	12.6	--	--	--	113.1	24	25.6	124.9	24	52.8
July	4	--	--	--	--	--	--	98.8	115	11.7	--	--	--	104.2	23	6.7	95.3	25	8.6
August	1	--	--	--	--	--	--	105.3	178	13.3	--	--	--	111.8	25	6.7	116.1	25	27.5
August	2	--	--	--	--	--	--	106.0	117	15.3	--	--	--	110.6	23	6.0	85.6	25	8.1

Table 5-8. Weekly mean total lengths (in mm) of salmon, herring, and smelt taken by purse seine in North Skagit Bay from June 8 to August 15, 1972

Month	Week number	Chinook salmon			Coho salmon			Smelt			Herring		
		$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD	$\bar{X}$	N	SD
June	2	--	--	--	153.5	4	6.2	157.8	21	11.9	143.9	54	18.4
June	3	133.7	10	7.6	--	--	--	159.0	25	6.2	178.5	13	19.2
June	4	109.5	2	6.4	--	--	--	153.2	12	6.8	155.8	32	17.1
June	5	83.6	14	7.1	80.5	4	3.9	134.9	22	26.6	167.6	54	20.0
July	1	87.0	2	1.4	100.0	3	9.5	144.8	9	7.3	160.2	41	13.1
July	2	142.5	2	46.0	--	--	--	139.3	50	28.7	170.0	50	25.3
July	3	90.0	4	6.7	--	--	--	119.7	31	7.2	163.2	3	11.0
July	4	105.8	58	14.9	--	--	--	129.6	34	28.1	135.1	25	38.4
August	1	109.7	13	13.1	--	--	--	135.2	25	19.2	162.6	25	18.9
August	2	131.3	33	23.7	--	--	--	150.4	25	28.9	106.0	25	18.1

growth in a few of the last migrants. The length frequencies of chinook salmon show constant recruitment and some increase in size in August. The mean weekly length frequencies of smelt and herring probably indicate the occurrence of at least two age classes in the catch during the sampling period.

Pink and chum salmon were not taken by purse seine in significant numbers because of the large mesh sizes. The mean weekly length frequencies of chinook and coho salmon, herring, and smelt taken by purse seine were generally larger than of those taken by townet. Chinook salmon taken by townet ranged in total length from 84 to 106 mm, whereas those taken by purse seine ranged from 83.6 to 142.5 mm. Coho salmon taken by townet ranged in length from 83.9 to 107.2 mm; by comparison those taken by purse seine ranged from 80.5 to 153.5 mm. Herring captured by purse seine were also larger, ranging from 106 to 178.5 mm, than those caught by townet, which ranged from 85.6 to 157.3 mm. Although the townet appears to have been less effective than the purse seine in sampling the larger individuals of these species, its use as the major sampling gear was the best choice since it most effectively sampled the smaller individuals which are more vulnerable to entrainment in the proposed once-through cooling water system.

5.3.6 Marked Chinook Salmon Recoveries

The Washington State Department of Fisheries released a total of 121,919 adipose-clipped juvenile chinook salmon marked with coded wire cranial tags from the Nooksack River Hatchery and 163,603 similarly marked juvenile chinook salmon from the Skagit River Hatchery during May, June, and July of 1972. A total of 42 of the fish in these two groups were recaptured in the surface tows, midwater tows, and purse seine hauls (Table 5-9). Thirty-eight of the 42 fish recaptured were from releases on June 15 and July 11 from the Skagit River Hatchery and the remaining four recaptured were from releases on May 18 and June 16 from the Nooksack River Hatchery. Twenty-one of the 42 fish recaptured were taken in Similk Bay where sampling effort was most concentrated, and 19 of these 21 fish recaptured in Similk Bay were from the Skagit River Hatchery releases and the remaining two were from the Nooksack River Hatchery. The first recaptures from the fish released

Table 5-9. Recoveries of tagged chinook salmon in North Skagit Bay during 1972 from releases by the Washington State Department of Fisheries

Area of release	Skagit Hatchery		Nooksack Hatchery		
Date of release	June 15	July 11	May 18	May 18	June 16
Size at release (mm)	138	102	108	108	53
Number released	97,117	66,486	3,001	69,806	49,112
Recaptures per area					
Swinomish Channel	4	1	0	0	0
Similk Bay	14	5	0	1	1
Hope Island Bay	4	2	0	0	1
Hope Island - mouth Swinomish Channel	2	2	0	0	1
Mouth Swinomish Channel - Buoy #8	1	3	0	0	0
Total	25	13	0	1	3

from the Skagit River Hatchery occurred 11 days after release, and recovery of marked individuals from both groups continued until the end of the sampling period.

Three of the four fish from the Nooksack River Hatchery plants were recaptured during the second week of August and one was recaptured on July 13. The recapture of four Nooksack River Hatchery plants indicates a recruitment to the juvenile chinook population of North Skagit Bay from areas other than the Skagit River.

5.4 SUMMARY AND CONCLUSIONS

1) The occurrence of large numbers of commercially valuable juvenile pink and chum salmon in North Skagit Bay present a difficult problem in the design and placement of an intake structure which will minimize the entrainment of these small salmonids. Therefore, this work was designed to determine their timing and relative abundance both vertically and horizontally in North Skagit Bay. The distribution and relative abundance of chinook and coho salmon were also determined along with several resident pelagic marine species.

2) A comparison of the townet catch per unit effort of pink and chum salmon established the seasonal relative abundance of these species in 1970, 1971, and 1972. Both species occur concurrently each year beginning to run in late March, reaching a maximum in early May and declining in numbers through early June. Pink salmon predominate during even years while chum salmon predominate during odd years.

3) Minimum weighted relative abundance estimates of juvenile pink and chum salmon in Similk and Hope Island Bays showed that the greatest numbers occur along the shoreline migration routes of North Skagit Bay during emigration. Estimates inshore and offshore indicated pinks were more abundant inshore during the 1970 and 1972 seasons while chums were about equally abundant in either area during 1971.

4) The salmonids are distributed largely in the surface layers. Of the pink, chum, and chinook salmon caught 96.7, 87, and 93.8 per cent, respectively, occurred at the surface (0-10 ft) with the remainder occurring at the 30 ft and 60 ft sampling depths.

5) A comparison of the townet catch per unit effort of chinook salmon established the seasonal relative abundance in 1970 and 1972. Wild juvenile chinook occurred in the catch during mid-May. Both wild and hatchery chinook occurred in the catch through the termination of sampling July 27, 1970 and August 15, 1972. In 1970 hatchery chinook were released in the North Fork of the Skagit River near the mouth and from the Skagit River Hatchery approximately 50 miles upstream in 1972, it was 3 and 11 days, respectively, before the hatchery stock began entering the catch. The greatest abundance of chinook salmon followed releases from the Skagit River Hatchery in June and July.

6) A comparison of the townet catch per unit effort of coho salmon established the seasonal relative abundance during 1970, 1971, and 1972. Coho salmon first appeared in the catch in early May, increased as the pink or chum salmon populations decreased until mid-June and then declined rapidly. A limited number of stomach samples indicated yearling coho feed on pink and chum salmon.

7) A comparison of the townet catch per unit effort of smelt and herring in 1972 indicated both species were relatively more abundant in March and early April and again after July 20. Lowest abundance occurred during the period of freshet from the Skagit River probably a result of the preference of these marine species for higher salinities. The greatest abundance of both species occurred in Similk Bay.

8) The vertical distribution of herring and smelt indicated that about 45 per cent of the herring occurred at both the 30 ft and 60 ft depths with about 10 per cent at the surface. Of the smelt 55 per cent were caught at 30 ft, with 19 per cent at the surface and 26 per cent at 60 ft.

9) Pelagic fish both anadromous and resident were generally always most abundant in Similk Bay in the three years of sampling.

10) Sand lance were found most abundant in the Swinomish Channel with smelt and herring in decreasing order. Pink, chum, chinook, and coho salmon were also found to occur.

11) A purse seine was utilized to supplement townet sampling during 1972. Although it did capture larger individuals of chinook and coho salmon, herring and smelt, purse seine sampling was less effective due to restrictions imposed by depth and time required per set and the extreme tidal velocities. Townet samples produced the best results for this study since this gear was selective for the smaller fishes which are most vulnerable to entrainment.

12) Length frequency measurements of pink, chum, and chinook salmon generally indicated constant recruitment throughout the migration period and compared similarly with data taken in 1970 and 1971. Length frequencies of coho salmon, herring and smelt determined their relative size.

13) Mark recoveries of chinook salmon in 1972 found 38 recaptures from releases from the Skagit River Hatchery and four recaptures from the Nooksack River Hatchery, suggesting that some recruitment of chinook salmon does occur from outside Skagit Bay.

14) There are at least two possible approaches to the design and placement of a once through cooling intake structure in this area which would minimize the entrainment of juvenile salmonids. The surface orientation of about 90 per cent of the juvenile pink, chum, and chinook salmon to the upper 10 ft of the water column would logically dictate the placement of an intake equipped with a low velocity design to draw cooling water from a horizontal direction at at depth of approximately 60 ft. However, it is quite likely that large numbers of resident juvenile pelagic marine species (i.e., smelt and herring) or demersal marine fishes may be entrained in a deep intake and thus a fish screening and return system would be required onshore. An alternative approach is to develop a positive solution to the entrainment and impingement of larval and juvenile fishes, a problem common to all water use industries. Associated with this project has been the on-site testing of a model rapid sand filter to determine the design parameters necessary in applying this concept as a positive solution to the entrainment of larval and juvenile fishes. This work is detailed in a separate report by Stober, Hanson, and Swierkowski (1973). An engineering design concept was developed from this study by Strandberg (1972) for a high capacity sand filter which would provide an effective solution to the entrainment and impingement of small fishes and thus eliminate the only major impact of once-through cooling on the marine ecosystem at this site.

6.0 PELAGIC EGGS AND LARVAL FISH OF SKAGIT BAY

by

J. E. Blackburn

6.1 INTRODUCTION

The steam electric generating plant proposed for Kiket Island would require 1,500 cfs of cooling water in a once-through cycle. The result can be the entrainment of important ichthyoplankton organisms into the system and their subsequent exposure to the potentially detrimental effects of changes in temperature and pressure, mechanical stresses and intermittent application of biocides. Intake screens are usually not satisfactory in preventing the passage of these small organisms. Therefore, knowledge on the temporal and spacial distribution and abundance of the ichthyoplankton becomes essential in the assessment of entrainment problems of the more important organisms. In this study a survey was made of the ichthyoplankton of the Skagit Bay area of Puget Sound from the north end of Saratoga Passage to Rosario Strait.

The previous work in Puget Sound has been restricted largely to specific subjects: Hickman (1959) described the larval development of the sand sole *Psettichtys*; English (1961, 1969) has done work on flatfish eggs; Orsi (1965) described the embryology of the English sole *Parophrys*. Waldron (1972) conducted the only comprehensive study of ichthyoplankton in Puget Sound. Beyond the limits of Puget Sound, a few more studies have been reported; Parsons, LeBrasseur, and Barraclough (1970) list months of occurrence of larvae and juveniles of 27 taxa in the Strait of Georgia; LeBrasseur (1970) and Aron (1958) list occurrences of larval fish in zooplankton and midwater trawl samples, respectively, in the Northeastern Pacific Ocean. Surveys of North Pacific ichthyoplankton are in progress at the present time in conjunction with the work of MARMAP.

The frequency and duration of sampling, together with the completeness of identification achieved, make this ichthyoplankton survey the most thorough yet conducted in any area of the Northeast Pacific. Most of the larval forms presented have never been described in the literature, and one is new to

Puget Sound. Many taxonomic problems have been solved, and this progress, together with the increased knowledge of larval distribution, will facilitate further work.

6.2 DESCRIPTION OF STUDY AREA

The physical characteristics of Skagit Bay are strongly influenced by the discharge from the Skagit River. The alluvial plain is fringed by an extensive tidal flat that extends toward Saratoga Passage and Whidbey and Hope Islands. Through this alluvium a current-scoured channel extends from the vicinity of Strawberry Point to Deception Pass.

The tidal currents in the scour channel between Saratoga Passage and Rosario Strait are both strong and complex. The complexity arises primarily from the fact that the tide enters Saratoga Passage after passing around the south end of Whidbey Island and thus is delayed by about 2 hr at Yokeko Point. This delay generates a difference in water level across Deception Pass and the attendant current flow. Thus, Saratoga Passage fills from and empties toward the south, whereas Deception Pass spills into and drains from Skagit Bay in the other direction. While the tide is flooding in both Saratoga Passage and Deception Pass, the water flows toward a node located between Strawberry Point and Goat Island. However, after the tide begins to ebb at Deception Pass there is a period of about 2 hr when the flood tide in Saratoga Passage and the ebb tide at Deception Pass reinforce each other and a net northward flow results, moving water from Saratoga Passage into Skagit Bay and through Deception Pass. Similarly, at the beginning of the Deception Pass flood current a southerly flow occurs.

Superimposed upon the tidal pattern is a net northerly flow, expressed as an excess of ebb over flood at Deception Pass with an annual mean of about 30,000 cfs. This flow displays a seasonal variation with a maximum of 70,000 cfs measured in March 1972 and a minimum of 5,000 cfs in August. The mean transport rate through Deception Pass is 140,000 cfs, and when the tidal range is 10.5 ft the transport is 220,000 cfs. The mean ebb velocity is 0.6 knots greater than the flood (Gene Colias, personal communication).

6.3 MATERIALS AND METHODS

The collections for this study were made with two basic types of gear, a vertically hauled 1/2-m plankton net and a horizontally hauled "townet."

6.3.1 Plankton Sampling

Plankton samples were taken with a conical 1/2-m net equipped with a TSK (Tsurumi-Seiki Kosakusho Co., Ltd.) flowmeter, #1015 or #2546. The flowmeter was mounted midway between the center and the rim of the net, as recommended by SCOR-ICSU (1966). The net was of No. 2 mesh (21 meshes per cm, 54 per inch) Nitex and was dyed dark green. A large weight (27 kg or 45 kg in very swift currents) was suspended below the net by a bridle of three ropes attached to the rim, and the cup was held in place by a cord attached to the weight.

Plankton samples were taken immediately after a Nansen cast had been made for temperature and salinity samples. Two replicate vertical hauls from the bottom to the surface were alternated with two replicates from a depth of 5 m to the surface. Two hauls from bottom to top were made in Similk Bay since it was only about 5 m deep.

Samples were taken with the boat either anchored or adrift. The net was lowered vertically at about 1 m/sec until the weight hit bottom; then it was retrieved at a rate as nearly standard as possible for the particular boat. The time that the net began ascent, the depth that the rim had reached, the duration of the haul to a tenth of a second, the flowmeter revolutions, and the wire angle were recorded. After the net was retrieved, it was rinsed from top to bottom with a hose, and the sample was transferred to a 473-ml (16 oz) large-mouthed jar, and Formalin was added to make a 3 per cent solution. The second haul was identical, with the exception that the depth was only 5 m. The procedure was then duplicated for the replicates.

The rate of ascent was approximately 1 m/sec on the R.V. *Onar*, 0.87 m/sec on the R.V. *Hoh*, 0.5 m/sec for samples taken from a 4.6-m skiff, and about 1.75 m/sec from the R.V. *Commando*.

The major portion of the samples was taken in conjunction with tri-weekly oceanographic cruises by the University of Washington Department of Oceanography during the calendar year 1971. After the termination of these

cruises, sampling was continued approximately monthly. The cruise schedule is given in Table 6-1.

Dewey, Goat Island, and Strawberry Point, (Fig. 6-1) were usually sampled on flood tide and ebb tide on each cruise. Polnell Point, Deception Island, and Similk Bay (Fig. 6-1) were sampled at least once on most cruises. On several occasions a station was sampled at 1-hr or 2-hr intervals for periods up to 24 and 48 hr.

6.3.2 Townetting

6.3.2.1 Large Net

The gear is described in the preceding section (5.0 JUVENILE SALMONID MIGRATION). Tows were 10 or 15 min in duration, and after they had been completed the trawl was completely retrieved and pulled aboard the boat. The cod end was then opened and the catch dumped into a bucket of water. The cod end was turned inside out through the zipper opening and rinsed in a bucket of water. The salmonids and debris were removed from the sample, and the remainder was poured through a small dip net with 0.9-mm bar mesh. The sample was put into a 473-ml (16 oz) wide-mouthed jar and preserved with 5% Formalin.

The townet was fished along three transects near Skagit Island (Fig. 6-1). A sampling period began about noon with one traverse of each transect at the surface, then one of each at 9 m and finally one of each at 18 m. This procedure was repeated again before dark for 18 daylight tows. The same schedule was then repeated once at night for a total of 27 tows.

6.3.2.2 Small Net

A smaller townet was developed at the end of May 1971, when the townet sampling for salmonids had ended. It was similar to that described by Clarke (1969), but had no opening-closing device. The net had a mouth opening of 1.2 m by 2.1 m and was made of a single layer of 3 mm knotless nylon lined with 3-mm ace mesh. The net was towed by a 4.6-m skiff at about 5 km/hr. Sampling with the small townet was conducted along a transect between the west end of Skagit Island and Yokeko Point (Fig. 6-1). All tows were 15 min in duration and at depths of approximately 6, 12, and 18 m.

Table 6-1. Schedule of sampling cruises

Cruise number	Date	Vessel	Number of samples	Filtration efficiency
1	26 Jan 71	Skiff	19	.78
2	20 Feb 71	Skiff	11	.81
341	2-4 Mar 71	Onar	37	.79
345	19-27 Mar 71	Onar	208	.822
3	8 Apr 71	Skiff		
560	13-15 Apr 71	Hoh	40	.818
4	23 Apr 71	Skiff	4	
5	29 Apr 71	Skiff	4	
565	4-6 May 71	Hoh	34	.753
6	14 May 71	Skiff	6	
7	20 May 71	Skiff	2	
357	26-28 May 71	Onar	34	.769
8	4 Jun 71	Skiff	4	
579	15-17 Jun 71	Hoh	100	.805
590	6-8 Jul 71	Hoh	86	.761
594	27-29 Jul 71	Hoh	54	.764
600	17-18 Aug 71	Hoh	34	.797
603	7-9 Sep 71	Hoh	28	.779
375	6 Oct 71	Onar	28	
9	5 Nov 71	Skiff	4	
10	17 Nov 71	Skiff	20	
11	28 Dec 71	Skiff	20	.881
12	23 Jan 72	Skiff	16	.901
13	17-18 Feb 72	Commando	36	.967
	24 Feb 72	Skiff	4	.925
14	27-28 Mar 72	Skiff	20	.889
15	11-12 Apr 72	Commando	44	.951

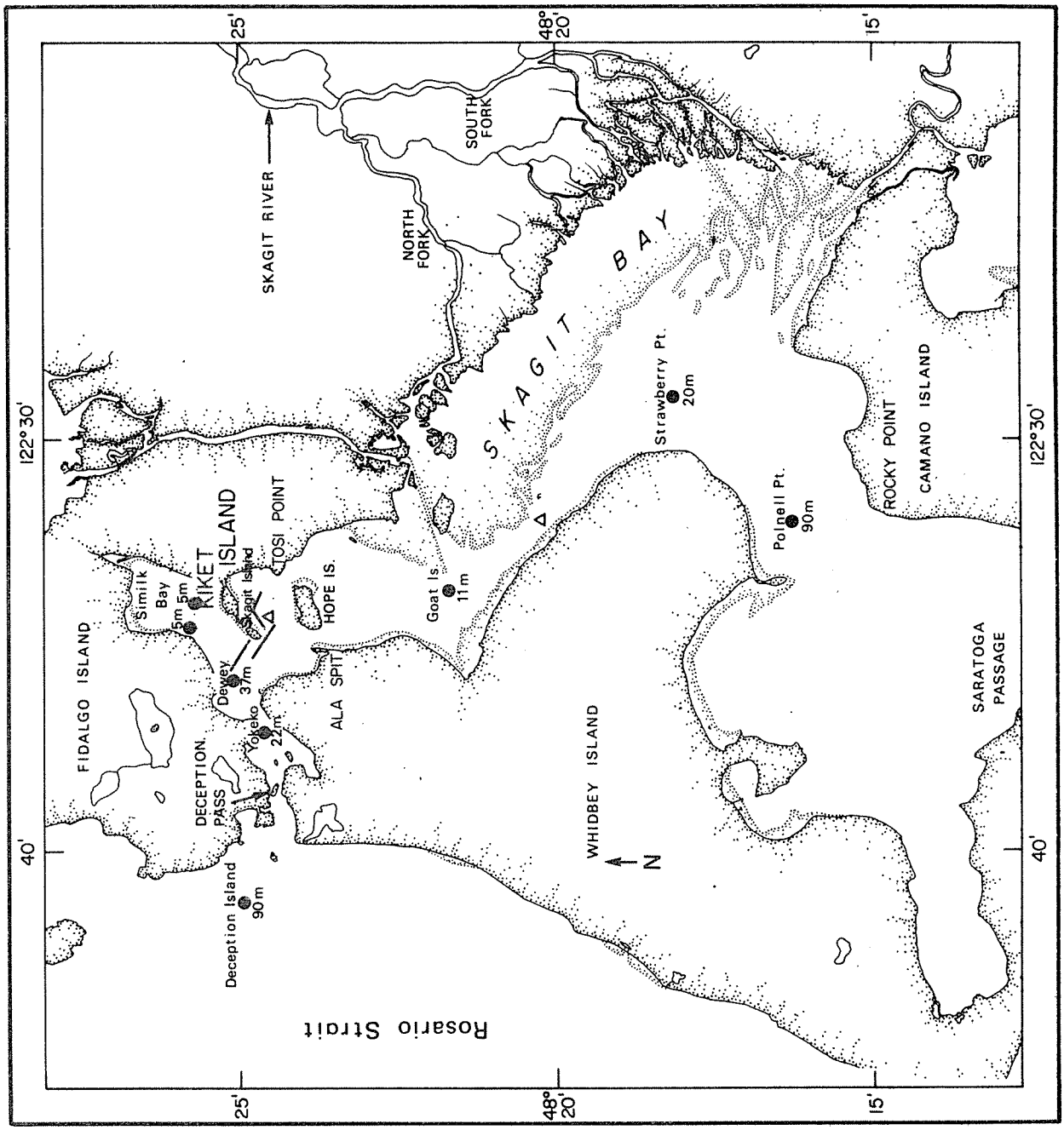

Fig. 6-1. Map of area showing sampling locations. Open triangle south of Goat Island is Buoy 8.

6.3.3 Sample Storage and Sorting

All samples were stored in cardboard boxes in the dark so that bleaching by sunlight would be minimized. During sorting the entire sample was placed in a pan painted flat black and examined under strong light. Fish eggs and larvae were removed and stored in 2-dram glass vials in a solution of 3-5 per cent salt-water Formalin.

A portion of the plankton samples was sorted a second time under a stereoscopic zoom dissecting microscope at 7 power so that a check would be provided on the efficiency of sorting. A total of six larvae and four eggs was found in 50 samples checked where 115 larvae and 348 eggs had been found originally.

6.3.4 Identification of Organisms

The eggs and larvae were sorted initially into different types; and examples of each, including the different sizes, were kept in a reference collection, which is on hand. Taxa were separated on the basis of perceivable differences in body form, pigmentation, and meristics. The most useful meristic characteristics were myomere counts, both abdominal and caudal, and finray counts. Identifications were made by comparison with published material and by the use of adult characteristics in the case of juveniles. Photographs were taken of specimens of many taxa, and these were also used as references in identification. An accounting was kept of species of which larvae had been found.

Several taxonomic problems remain.

1) Osmeridae (smelt): The larvae of both the predominant species in Skagit Bay have been described; but three other species which are rare have been recorded in Puget Sound (DeLacy, Miller, and Borton, 1972).

2) Gadidae (codfishes): Larvae belonging to *Microgadus proximus* (Pacific tomcod) and *Gadus macrocephalus* (Pacific cod) may be confused.

3) Pleuronectidae (righteyed flounders): Probably all are currently separable.

4) The families Cottidae (sculpins), Agonidae (poachers), Cyclopteridae (snailfish), Gobiidae (gobies), Pholidae (gunnels), and Stichaeidae (pricklebacks) are all separable, but within each family, problems of separation may yet exist.

6.3.5 Calculation of Sample Volumes

TSK flowmeter #1015 was used until it was lost overboard on the cruise in October 1971 and was not calibrated during this study, therefore the equation determined by Peck (1969) for this flowmeter was used to calculate the volumes sampled:

$$\text{Velocity } \left(\frac{\text{Meters}}{\text{Second}}\right) = .03554 + .12926 \times \frac{\text{Revolutions}}{\text{Second}}.$$

Flowmeter #1015 jammed during about 1 tow in 4. The missing volumes were estimated from the efficiency of filtration. Efficiency of filtration was calculated for the tows on which the flowmeter worked by the equation:

$$\frac{\text{Distance traveled as indicated by the flowmeter.}}{\text{Depth of haul}}$$

Clogging did not appear to affect the efficiency of filtration since successive tows were not progressively less efficient and deeper tows were not less efficient than shallow tows. However, the efficiency of filtration did increase as wire angle increased beyond 25°. A regression of the efficiency of filtration versus wire angle for observations with a wire angle greater than 25° was used to estimate efficiencies. The volume sampled was then estimated by:

$$\text{Volume} = \begin{matrix}\text{estimated} \\ \text{filtration efficiency}\end{matrix} \times \begin{matrix}\text{depth} \\ \text{of tow}\end{matrix} \times \begin{matrix}\text{mouth area} \\ \text{of net}\end{matrix}$$

Flowmeter #2546 was obtained as a replacement in December 1971. The factory calibration was checked by procurement of vertical hauls from a known depth at a known rate without the net attached. Since the distance traveled by the flowmeter agreed well with the distance traveled as estimated by the factory calibration, the factory calibration was used to calculate volumes filtered. A comparison of efficiency of filtration rates indicated that volumes estimated by flowmeter #1015 were 12 per cent to 15 per cent below those estimated by #2546. The meter was lost in October 1971 and replaced in December, a period during which only five individuals were captured,

therefore no attempt was made to correct for the differences since it only affected comparisons between years.

Cruises were kept separate in the analyses because of different rates of ascent and different densities of plankton.

6.3.6 Sample Variation

Analysis was conducted of within-station[1] variation in abundance of 1-mm flatfish eggs, as an index of variance of all groups. All stations were grouped by location and type, whether surface or deep. All regularly sampled locations were included in the analysis (Dewey, Goat Island, Strawberry Point, Polnell Point, Deception Island, and Yokeko), but only stations with a total catch of three or more 1-mm eggs in a pair of hauls and at least one in each haul were used. One was not added to the counts before transforming to logarithms since it would reduce the variance, especially for small counts.

All the paired hauls were pooled and the assumptions that the transformations used were proper and the variance was equal at all locations were tested.

Correction for differing amounts of water filtered was applied to the data by the following formula:

$$\text{Standardized catch per tow} = \frac{\text{Number of eggs in tow i (Volume, tow 1 + Volume, tow 2)}}{2\ \text{(Volume in tow i)}}$$

Volume, flowmeter revolutions and station depth were used to standardize the catch per tow.

6.3.7 Unit of Measure

Plankton data are commonly standardized to number per unit volume or number per unit sea surface. The number per unit volume is an underestimate of actual abundance when vertical samples are taken through a stratified population, whereas the number per unit sea surface is an underestimate only when the net does not go as deep as the target organisms.

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[1]Station = all samples taken at one location and time, usually two vertical hauls from the bottom and two from 5 m.

There is no reason to believe that either standardization is superior throughout an area that varies in depth and extent of tidal flushing as the sampling area does; therefore each standardization has been used where it was deemed most appropriate.

The data are presented as number per one m^2 or m^3 rather than 10 m^2 or 1,000 m^3 because the volumes sampled are small, usually less than 10 m^3 for a single tow (about 0.9 m^3 per surface tow), and the large denominator would inflate the actual catch far out of proportion to reality.

6.3.8 Tidal Classification

All samples were classed according to the tidal stage during which they were taken. Deception Pass current tables (U.S. Dep. of Commerce, 1970, 1971) were used. Corrections for local variations were obtained directly from strip chart records of continuous recording current meters placed in Skagit Bay by the University of Washington Department of Oceanography. The tides were separated into six stages: first hour of flood, flood, last hour of flood, first hour of ebb, ebb, and last hour of ebb. This separation allowed comparison of samples obtained during ebb and flood without the more heterogeneous period of tidal change masking the trends. In some cases, the results were pooled into ebb and flood.

6.3.9 Egg Staging

All eggs were staged by comparison with Budd (1940) Plates 1a and 2. Stages were separated as follows: Stage 1, fertilization to early blastodermal cap; Stage 2, completed blastodermal cap; Stage 3, appearance of the segmentation cavity to the germ ring enclosing about 1/3 of the yolk; Stage 4, 1/3 epiboly to closure of blastopore; Stage 5, closure of blastopore to extension of tail 3/4 circle around the egg; Stage 6, tail more than 3/4 circle around the egg; and Stage 7, destroyed or unstageable. Stage 1 eggs were further separated according to the number of cells in the embryo: precleavage, 2, 4, 8, 16, and more than 16 cells. The ages of English sole (*Parophrys vetulus*) at these stages of development are given in Table 6-2.

Table 6-2. Ages of the eggs of *Parophrys vetulus* at different stages of development after artificial fertilization and incubation at about 13.0 C (Budd, 1940)

Stage	Maximum age, in hours
1	10
2 cells	2
4 cells	3
8 cells	4
16 cells	5
2	23
3	30
4	about 49
5	70
6	90

6.4 RESULTS AND DISCUSSION

6.4.1 Description of Catch

The plankton net caught pelagic fish eggs and young larvae. Specimens varied in size for different species, from 2 mm to 18 mm; but generally the youngest stages were captured. The townet captured larger individuals, generally late larval, and juvenile stages, ranging in size from 7 mm to 40 mm or greater.

6.4.2 Predominant Species in the Plankton

During the 16-month study from January 1971 to April 1972, 897 samples were collected. These yielded a total of 4,602 specimens, and these specimens were separated into seven fish egg and 43 larval taxa (Table 6-3; several taxa have been combined). The numbers of individuals and numbers of positive tows show a maximum abundance in March and April of 1971 and 1972 and a minimum abundance in November and December 1971.

The taxa tended to show associations in time of occurrence. For most taxa, those that occurred before May 1971 were virtually absent after, and vice versa.

Ten taxa contributed 88.3 per cent of the catch in the entire study period. Listed in order of decreasing numbers captured, they were: 1-mm flatfish eggs, cod larvae (*Gadus-Microgadus*), Pacific sand lance (*Ammodytes hexapterus*) larvae, starry flounder (*Platichthys stellatus*) larvae, Pacific herring (*Clupea harengus pallasi*) larvae, northern anchovy (*Engraulis mordax*) eggs, Pacific hake (*Merluccius productus*) eggs and larvae, smelt (*Osmeridae*) larvae, sanddab (*Citharichthys* sp.) eggs, and rockfish (*Sebastes* sp.) larvae.

The abundance of larvae is more comparable as an estimate of relative dominance. Thus ten taxa contributed 80.4 per cent of all larvae, and these were, in order of decreasing numbers captured: cod, Pacific sand lance, starry flounder, Pacific herring, smelt, Pacific hake, rockfish, English sole (*Parophrys vetulus*), prickly sculpin (*Cottus asper*), and gobies (Gobiidae).

The absence of northern Anchovy larvae from the plankton samples while their eggs were abundant is somewhat puzzling. The larvae may have been present and not sampled because of avoidance, extrusion, or escape. However, avoidance is unlikely for the smallest hatchlings because of their

limited mobility on account of the large yolk sac. Isaacs (1965) reported that avoidance became important at about 9.75 mm for this species in the California current. Escape through the 202-μ mesh was unlikely. Vannucci (1968) indicated that the point of 50 per cent retention is 118 per cent of the mesh width for fish eggs and glass beads. This would mean 238 μ for this net. Newly hatched anchovies are about 700 μ across the yolk sac and those with yolk sac absorbed are about 320 μ across at the head (estimates made from drawings in Bolin, 1936). Extrusion was even more unlikely since all hauls were relatively short and slow, as the very low frequency of damaged larvae would indicate. The only conclusion is that the larvae were not present in appreciable numbers.

Ahlstrom (1959) reported from a study of vertical distribution off Southern California and Baja California that 95 per cent of all anchovy larvae occurred within the temperature range of 14.0 C to 17.4 C. His haul data indicated that the layer of water 14 C and warmer usually extended to 15 to 40 m deep. Richardson (in press) reported that anchovy larvae were abundant in the Columbia River plume but were always associated with water 14 C or greater. At Polnell Point and Strawberry Point surface water temperatures above 14 C were not measured until late July. At this time the surface water temperature was 17.5 C and the temperature at 5 m was 10.3 C; thus a much thinner layer of water with suitable temperature existed than Ahlstrom reported. Salinity was rather low at the surface also, ranging from 7.99 °/oo to 18.09 °/oo where temperature was over 14 C, and rapidly increased to about 26 °/oo at 5 m. It appears that anchovy eggs were always found in the upper 5 m since in all cases surface hauls had essentially the same number of eggs as deep hauls.

It is possible that survival is quite low for northern anchovy in this area since this species primarily reproduces in the ocean, where both temperature and salinity regimes are much different. It has been shown that for several marine fishes certain combinations of temperature and salinity are necessary for survival of the eggs until hatching (Alderdice and Forrester, 1971*a* and 1971*b*). Some anchovy larvae and juveniles were captured in townet samples on several occasions but always in very small numbers. Had this species reproduced significantly in the study area, abundance would

have been comparable with that of the herring. The lack of anchovy larvae in the plankton samples appears to be best explained by a high mortality rate.

The plankton catches indicated that there were two hatches of herring, one in March and April and one in late May and early June (Table 6-3). The first hatch was most abundant between Strawberry Point and Dewey, and the second was most abundant at Deception Island (Table 6-4).

6.4.3 Distribution of Plankton

Virtually no taxon was distributed evenly over the study area, and each displayed a maximum abundance at one location (Table 6-5). Thus each location had a characteristic assemblage; especially different were Saratoga Passage (Polnell Point) and Rosario Strait (Deception Island), each of which yielded at least seven taxa not found at the other. The biological difference between Saratoga Passage and Rosario Strait was consistent with the difference in water quality between the two areas. Rosario Strait generally had higher salinity and less stratification than at Saratoga Passage but the most important difference beween the two probably is the estuarine nature of Saratoga Passage. It is relatively enclosed, thus decreasing dispersion of vulnerable ichthyoplankton and it probably has a greater rate of food production because of inflow from the Skagit River. There appeared to be a greater standing crop of phytoplankton in Saratoga Passage than Rosario Strait (secchi disc readings at Polnell Point were 1-3 m and 5 m or more at Deception Island).

Six taxa contributed 95 per cent of the catch in Saratoga Passage (Polnell Point) and these were, in order of decreasing numbers captured: 1-mm flatfish eggs, Pacific hake larvae and eggs, northern anchovy eggs, starry flounder larvae, slender sole (*Lyopsetta exilis*) eggs and larvae, and English sole larvae. The larvae of four taxa contributed 75.7 per cent of all larvae taken, and these were, in order of decreasing numbers captured: Pacific hake, starry flounder, English sole, and slender sole.

Six taxa contributed 86 per cent of the catch in Rosario Strait (Deception Island), and these were, in order of decreasing numbers captured: 1-mm flatfish eggs, the larvae of cod, Pacific herring, rockfish, Pacific sand lance, and smelt.

Table 6-3. Vertical plankton tows and catch by sampling date and taxon

	1/26/71	2/20/71	3/3/71	3/20-27/71	4/13-15/71	4/23/71	4/29/71	5/4-5/71	5/14/71	5/20/71	5/27-28/71	6/4/71	6/15-18/71	7/6-8/71	7/27-29/71	8/17-18/71	9/7-8/71	10/6/71	11/5/71	11/17/71	12/28/71	1/23/72	2/14-24/72	3/27-28/72	4/11-12/72	TOTALS
Number of hauls																										
Deep hauls	13	6	16	100	18	4	4	15	6	2	17	4	44	42	26	16	14	14	2	10	10	8	20	10	22	443
Surface hauls			14	100	18			14			17		44	42	26	16	14	14	2	10	10	8	20	10	22	401
Other[1]	6	5	6	8	4			4					12	2	2	2		2								53
Number of positive hauls																										
Deep hauls														36	20	11	7	4	0	1	1	5	20	10	22	377
Surface hauls														12	12	8	2	0	0	0	0	1	11	9	11	236
Other[1]														1	2	1		0								20
Total individuals	16	10	96	2537	428	43	34	178	24	11	122	9	252	101	115	30	12	4	0	1	1	7	137	116	318	4602
Clupea harengus pallasi				22	27	2	2		2		5	8	65	5		1								8	15	162
Engraulis mordax eggs											27		52	23	50	9										161
Osmeridae	1	3	5	31	4	1	2	26	1	1	2		6										2	2	2	89
Gadidae																										
Gadus - Microgadus			4	192	25	11	6	6	4	3	2												2	27	53	335
Merluccius productus eggs				7	22			8			3															40
Merluccius productus			1	26	4			13	4	1	21															85
Pleuronectiformes																										
Citharichthys sp. eggs									1	1	1		20	23	14	8	5									73
Lepidopsetta bilineata				7																						7
Lyopsetta exilis eggs				10	13			2		1	1													1		28
Lyopsetta exilis				2	13		1	7			3															26

Table 6-3. Vertical plankton tows and catch by sampling date and taxon - continued

	1/26/71	2/20/71	3/3/71	3/20-27/71	4/13-15/71	4/23/71	4/29/71	5/4-5/71	5/14/71	5/20/71	5/27-28/71	6/4/71	6/15-18/71	7/6-8/71	7/27-29/71	8/17-18/71	9/7-8/71	10/6/71	11/5/71	11/17/71	12/28/71	1/23/72	2/14-24/72	3/27-28/72	4/11-12/72	TOTALS
Pleuronichthys sp. eggs									1		1			1												3
1-mm flatfish eggs		2	39	1904	208	11	5	73	3	4	45		41	18	26	4	4	2				4	68	67	190	2713
Isopsetta isolepis				10	2		1																			13
Parophrys vetulus	1		7	30	14	2	1	4	1														2	3	2	67
Platichthys stellatus			1	56	63	3	7	16			1		4												14	165
Psettichthys melanostictus				1	4	1		7	2				3					1								19
Hexagrammidae																										
Hexagrammos sp.	1			3																		1	1			6
Ophiodon elongatus				5																					3	8
Sebastes sp.			3	22	15	7	1	5	2		5		1			1									10	72
Cottidae																										
Cottus asper				1			1	6	2		2	1	25	17	3	1									1	60
Dasycottus settiger				1																						1
Hemilepidotus sp.																					1					1
Leptocottus armatus	1	1		9	1						1				1											14
Myoxocephalus polyacanthocephalus				1																						1
Unidentified cottid		1	2	24	3	3	3	1	1		1			2	2							1	4	3	7	58
Agonidae				4	1								1	1												7
Cyclopteridae			1	5	3	1							1	1			1			1			1	2	1	18
Gobiidae								1					20	8	18	6	2	1								56

Table 6-3. Vertical plankton tows and catch by sampling date and taxon - continued

	1/26/71	2/20/71	3/3/71	3/20-27/71	4/13-15/71	4/23/71	4/29/71	5/4-5/71	5/14/71	5/20/71	5/27-28/71	6/4/71	6/15-18/71	7/6-8/71	7/27-29/71	8/17-18/71	9/7-8/71	10/6/71	11/5/71	11/17/71	12/28/71	1/23/72	2/14-24/72	3/27-28/72	4/11-12/72	TOTALS
Ammodytes hexapterus	11	1	24	66	8																	1	49	1	11	172
Pholidae				8		1																			1	10
Stichaeidae																										
Lumpenus sagitta		1	7	32	2																		5		1	48
Xiphister atropurpureus																							1	1		2
Xiphister mucosus	1			1																						2
Unidentified stichaeid		1	2	26			4																2	1	5	41
1-mm demersal egg				30	1																					31
Mangled and unidentified				1				3			1		1												2	8

[1]All "other" hauls were in Similk Bay except two nonstandard hauls on March 3, 1971.

Table 6-4. Catches of herring larvae per plankton net haul by time period and location

Location n = number of hauls	Time period 1971 19 to 27 March	13 to 23 April	29 Apr to 14 May	20 to 28 May	4 to 17 June	6 to 8 July	1972 27 to 28 March
Deception Island n = 4, 2, 3, 2, 4, 2, 2.	0.0	.5	.33	.50	5.25	0.0	0.0
Dewey n = 6, 8, 12, 6, 12, 4, 4.	0.0	1.12	.33	.33	2.50	0.0	1.75
Goat Island n = 6, 4, 4, 4, 4, 4,-	0.0	1.75	0.0	0.0	0.0	0.0	
Strawberry Point n = 6, 4, 4, 3, 4, 4, 2.	0.83	1.50	0.0	0.0	.25	0.0	0.0

Table 6-5. Vertical plankton tows and catch by location and taxon

	Deception Island	Yokeko March 20-23 1971	Dewey	Similk	Skagit Island July 7-8, 1971	Goat Island	Buoy 8 June 15-16, 1971	Strawberry Point	Polnell Point	Other	Total
Number of hauls											
Deep hauls	29	72	129		26	56	24	53	32	22	443
Surface hauls	26	72	102		26	56	24	53	32	10	401
Other				51						2	53
Number of positive hauls											
Deep hauls	20	72	120		23	37	23	38	24	20	377
Surface hauls	15	72	53		6	33	12	20	21	4	236
Other				18						2	20
Total individuals	212	1,640	977	49	52	265	97	506	716	88	4,602
Clupea harengus pallasi	28	16	72	2	5	9	10	17	1	2	162
Engraulis mordax eggs			3		5	14	15	65	59		161
Osmeridae	7	19	21			12		23	3	4	89
Gadidae											
Gadus - Microgadus	59	135	123	1		6			3	8	335
Merluccius productus eggs						3		7	30		40
Merluccius productus	4	7	8			3	5	9	48	1	85
Pleuronectiformes											
Citharichthys sp. eggs	2		34	3	16	5	8	5			73
Lepidopsetta bilineata		7									7
Lyopsetta exilis eggs		1	1			1		5	20		28
Lyopsetta exilis		1	3			3		4	14	1	26
Pleuronichthys sp. eggs			2					1			3

Table 6-5. Vertical plankton tows and catch by location and taxon - continued

	Deception Island	Yokeko March 20-23 1971	Dewey	Similk	Skagit Island July 7-8, 1971	Goat Island	Buoy 8 June 15-16, 1971	Strawberry Point	Polnell Point	Other	Total
1-mm flatfish eggs	66	1,200	444	35	10	142	20	303	466	27	2,713
Isopsetta isolepis	1	10	1							1	13
Parophrys vetulus	2	15	11			7		8	18	4	67
Platichthys stellatus	4	44	35	2		12	3	32	32	1	165
Psettichthys melanostictus	2	1	4			6	1	1	4		19
Hexagrammidae											
Hexagrammos sp.		3	2							1	6
Ophiodon elongatus		5	3								8
Sebastes sp.	15	11	31			2		1	4	8	72
Cottidae											
Cottus asper	1	1	16		7	10	17	7	1		60
Dasycottus setiger		1									1
Hemilepidotus sp.			1								1
Leptocottus armatus		5	2			2		3		2	14
Myoxocephalus polyacanthocephalus		1									1
Unidentified cottid	4	20	21		2	2		2	4	3	58
Agonidae		2	2	1	1	1					7
Cyclopteridae	4	3	9							2	18
Gobiidae			8	2	6	15	17	6	2		56
Ammodytes hexapterus	8	53	81	2		4		3	2	19	172
Pholidae	1	6	2					1			10

Table 6-5. Vertical plankton tows and catch by location and taxon - continued

	Deception Island	Yokeko March 20-23 1971	Dewey	Similk	Skagit Island July 7-8 1971	Goat Island	Buoy 8 June 15-16, 1971	Strawberry Point	Polnell Point	Other	Total
Stichaeidae											
Lumpenus sagitta	2	26	16			1			1	2	48
Xiphister atropurpureus			2								2
Xiphister mucosus			1							1	2
Unidentified stichaeids	1	19	15	1		2			2	1	41
1-mm demersal egg	1	28						2			31
Mangled and unidentified			3			1	1	1	2		8

Between Strawberry Point and Yokeko, the plankton of Saratoga Passage and Rosario Strait were combined by the currents; but there were other taxa that occurred in maximum abundance within this area (Table 6-6): Pacific sand lance, smelt, sanddab eggs, snake prickleback (*Lumpenus sagitta*), prickly sculpin, gobies, and the unidentified stichaeid complex. Generally all cottids and Blennioids were most abundant in this area.

Krejsa (1967) notes that the prickly sculpin is found commonly in freshwater and migrates downstream to brackish water for spawning from February to June or July. The larvae remain pelagic for 30 to 35 days before they settle, but they do not reenter freshwater until September. This sculpin was the most abundant sculpin in plankton samples in Yaquina Bay (Sharon Myers and Dr. Sally Richardson, personal communication) Humboldt Bay (Stein, 1972) and in Skagit Bay. However, it has never been recorded in Puget Sound (DeLacy, Miller, and Borton, 1972).

The larvae of this species did not vary more than about 1 mm in length in the plankton samples and little more than that in townet samples. They occurred at all major sampling locations; thus it appears that the individuals captured were dispersing from the brackish water area around the Skagit River mouth. One 26-mm juvenile prickly sculpin was captured during tow-netting in September.

6.4.4 Description of Townet Catch

Of the hauls taken with the large townet between March 31 and May 26, 1971, 96 were examined; and these yielded 6,488 specimens belonging to 13 families and about 60 taxa (Table 6-7). Four families contributed the majority of the catch and these were with percentages of contribution: Pacific herring, 49.0 per cent; Pacific sand lance, 27.0 per cent; Cottidae, 8.2 per cent; and Stichaeidae, 8.0 per cent.

Forty-one tows of the small townet between June 4 and September 29, 1971 yielded 490 individuals belonging to 13 families (Table 6-8). Five families contributed 84.9 per cent of the total catch, and these were, in order of descreasing numbers captured: Pacific herring, 60.2 per cent; threespine stickleback (*Gasterosteus aculeatus*), 10.2 per cent; smelt, 7.8 per cent; righteyed flounders (Pleuronectidae), 4.1 per cent; and poachers (Agonidae), 2.7 per cent.

Table 6-6. Average catches per plankton net haul by location for all taxa of which 40 or more individuals were captured. Greatest density is underlined for each species

	Deception Island	Dewey	Goat Island	Strawberry Point	Polnell Point
Engraulis mordax eggs	--	0.06	0.35	1.22	3.69
Merluccius productus eggs	--	--	0.19	0.42	3.25
Merluccius productus	0.15	0.11	0.04	0.30	3.00
1-mm flatfish eggs	1.68	3.09	1.60	4.27	9.15
Parophrys vetulus	0.12	0.11	0.25	0.42	0.70
Platichthys stellatus	0.30	0.39	0.35	1.02	2.37
Osmeridae	0.22	0.26	0.39	0.82	0.08
Citharichthys sp. eggs	0.05	0.62	0.04	0.10	--
Cottus asper	0.00	0.23	0.25	0.21	0.07
Gobiidae	--	0.16	0.23	0.21	0.20
Lumpenus sagitta	0.19	0.32	0.06	--	0.12
Stichaeid unidentified	0.10	0.18	0.04	--	0.03
Ammodytes hexapterus	0.50	0.83	0.19	0.10	0.10
Gadus-Microgadus	3.67	1.46	0.13	--	0.10
Sebastes sp.	0.98	0.41	0.04	0.05	0.33
Clupea harengus pallasi	1.18	0.84	0.29	0.37	0.00

Table 6-7. Townet catch by major groups

	March 31	April 22	April 28	1971 May 5	May 13	May 19	May 26	Total
Number of hauls examined	16	11	10	14	16	18	11	96
Haul duration, minutes	10	15	15	15	10	10	10	
Total larvae	376	1,388	710	1,022	645	2,068	282	6,491
Clupea harengus pallasi	76	331	177	405	526	1,504	162	3,181
Osmeridae	18	20	42	14		4	15	113
Gadidae								
Gadus-Microgadus	2	8	7	12	9	27	8	73
Merluccius productus			1				2	3
Pleuronectidae								102
Hippoglossoides elassodon egg		3	4	3				10
Hippoglossoides elassodon		1	1			1		3
Isopsetta isolepis			6	2	1	4	4	17
Lepidopsetta bilineata		1	1	4			1	7
Lyopsetta exilis		1	1					2
Parophrys vetulus		4	7	5		4	2	22
Platichthys stellatus		4		5		16		25
Psettichthys melanostictus		1	1	4		8	2	16
Sebastes sp.	2	4	3	2				11
Hexigrammidae								14
Hexagrammos sp.	1	1	3			1		6
Ophiodon elongatus		2	3			3		8
Cottidae								535
Blepsias cirrhosus	1	1						2
Cottus asper			2	3		1		6
Dasycottus setiger		1	1					2
Enophrys bison			1	5		1		7
Gilbertidia sigalutes	5	1	1	1		7	1	16
Icelinus sp.							5	5
Leptocottus armatus				2				2
Myoxocephalus polyacanthocephalus			2	1				3

Table 6-7. Townet catch by major groups - continued

	March 31	April 22	April 28	1971 May 5	May 13	May 19	May 26	Total
Cottidae (cont'd.)								
Nautichthys oculofasciatus		1	8	3				12
Psychrolutes paradoxus	10	40	48	273	1	45	7	424
Radulinus asprellus	1							1
Rhamphocottus richardsoni	1	6	5	9		1		22
Triglops macellus						1		1
Unidentified cottid		7	5	10		9	1	32
Agonidae								54
Agonus acipenserinus		1	6	23		11		41
Unidentified agonid	1		3	5		3	1	13
Cyclopteridae	3		14	3	3	1		24
Gobiidae				1				1
Ammodytes hexapterus	66	778	262	140	98	347	64	1,755
Pholidae	6	22	11	1		1		41
Stichaeidae								521
Lumpenus sagitta	112	28	23	45		63	7	278
Xiphister atropurpureus	4	12	3	2				21
Xiphister mucosus	24	5	7			1		37
Unidentified stichaeid	14	100	42	20	5	4		185
Zoarciidae	1							1
Mangled and unidentified	28	4	9	19	2			62

Table 6-8. Catches of the small townet by major taxa and sampling dates

	June 4	June 23	June 29	July 23	Aug. 10	Aug. 25	Sept. 29	Total
Number of tows	2	4	8	4	6	9	6	
Total larvae	5	172	184	17	60	27	25	490
Clupea harengus pallasi		131	151	7	4	2		295
Engraulis mordax						1	5	6
Osmeridae		13	13		11	1		38
Gadus-Microgadus	2				2	4		8
Pleuronectidae								18
Hippoglossoides elassodon					1			1
Isopsetta isolepis			2					2
Parophrys vetulus			2					2
Platichthys stellatus		1						1
Psettichthys melanostictus		2	6	1	1	1	1	12
Gasterosteus aculeatus			1		35	4	10	50
Sygnathus griseolineatus						1		1
Cottidae								11
Cottus asper							1	1
Leptocottus armatus					1			1
Psychrolutes paradoxus					1	2		3
Unidentified cottid			1	1	1	1	2	6
Agonidae	3	1	2	3	1	2	1	13
Cyclopteridae		1	3	4	1	1	1	11
Ammodytes hexapterus				1				1
Stichaeidae						6	4	10
Zoarciidae					1			1
Unidentified		21	3			1		25

Herring larvae ranked behind cod and Pacific sand lance in abundance in the plankton samples but were by far the most abundant species in the townet collections. A possible explanation of the discrepancy is that they were available to the townet through most of their larval life, but were only available to the plankton net while with yolk sac and for a short time thereafter. Of the two populations of herring sampled by the plankton net, the first was most abundant between Dewey and Strawberry Point and dominated the townet catches (Fig. 6-2). No townet samples were taken outside Deception Pass so it is not possible to determine whether this population remains within Skagit Bay throughout its larval life, but it is a possibility.

The family of cods was the most abundant of the families found in the plankton and otter trawl catches (reported in section 9.0) and the sixth most abundant family in the townet collections. This dramatic shift must be due to unavailability to the townet. They were probably planktonic during most of the townet season since larval life began in March and April. Since the ratio of night catch of cod in the townet to day catch was nearly five to one and the greatest numbers were taken at 18 m, it appears that when cod are large enough to be retained by the townet they are associated with the bottom and come up at night.

6.4.5 Sources and Movements of Flatfish Eggs

This group, considered to be the spawn of English sole, starry flounder, sand sole (*Psettichthys melanostictus*), and butter sole (*Isopsetta isolepis*) (English, personal communication), was far more abundant than any other. The abundance by location and time is shown in Fig. 6-3. The greatest abundance was consistently at Polnell Point from February until the end of July.

The densities of 1-mm flatfish eggs in the waters above and below 5 m are shown in Figs. 6-4 and 6-5. Since the eggs are spawned on the bottom and have a positive buoyancy that causes them to rise to near the surface where they hatch in about 4 days (DeLacy, personal communication), it is not surprising that virtually all the eggs with 16 cells or less (5 hr old, Budd, 1940) were found below the upper 5 m.

Thus, Fig. 6-5 indicates that the eggs probably originated between Dewey and Polnell Point during March to April in 1971 and as early as February in 1972. However, in 1971, beginning on April 15 the youngest eggs

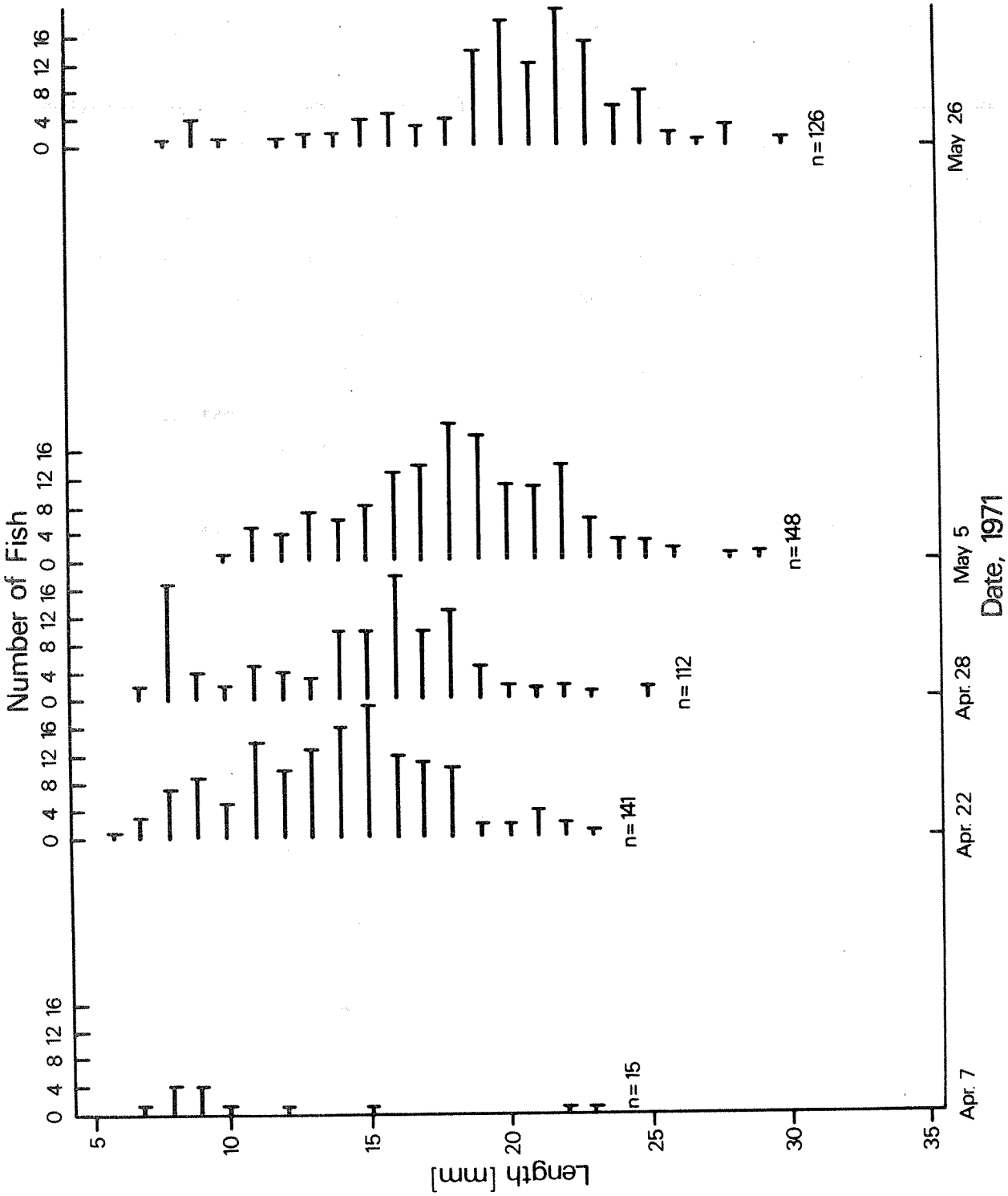


Fig. 6-2. Length frequency of larval herring from townet catches by date.

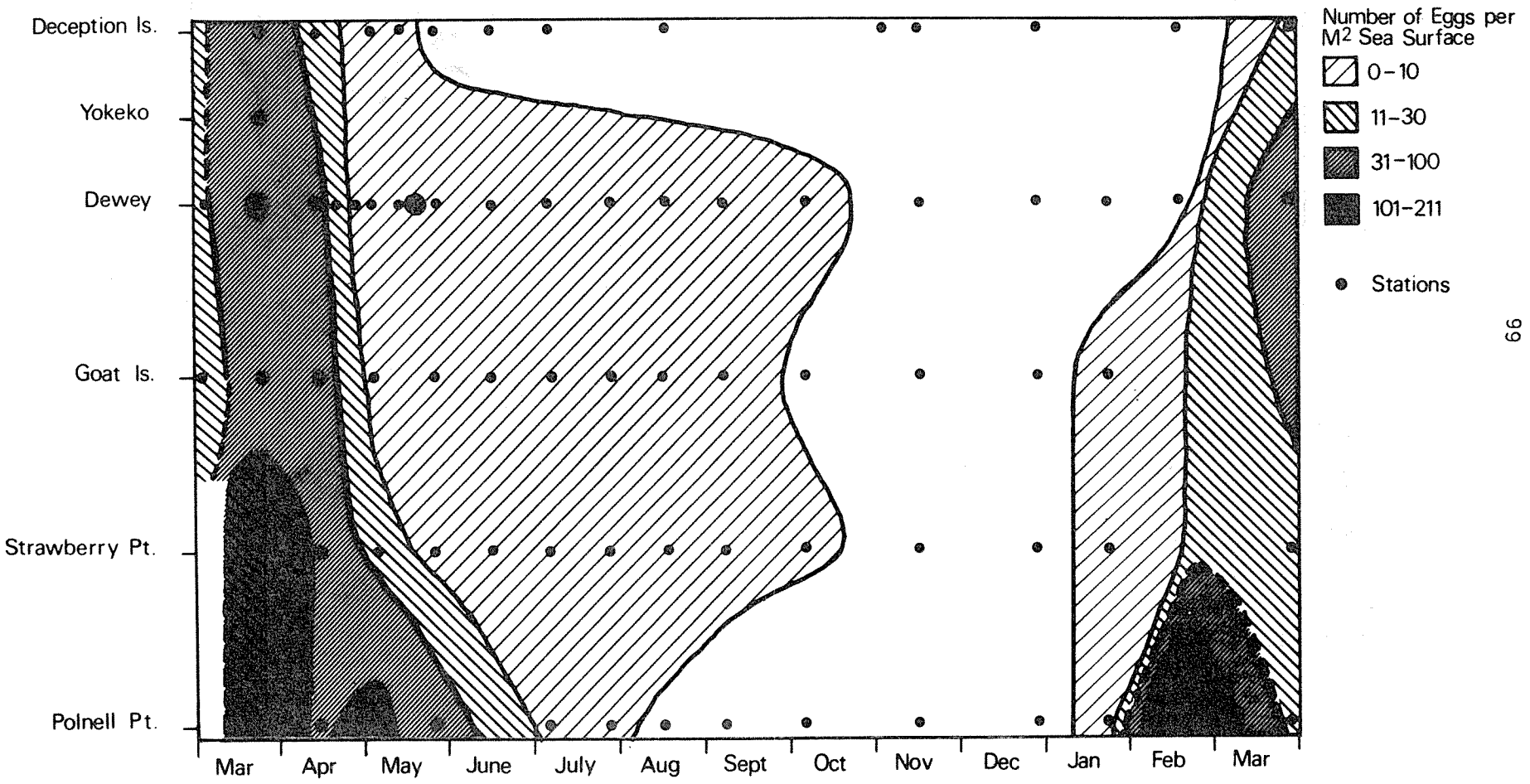


Fig. 6-3. Numbers of 1-mm flatfish eggs per m^2 of sea surface by location and date.

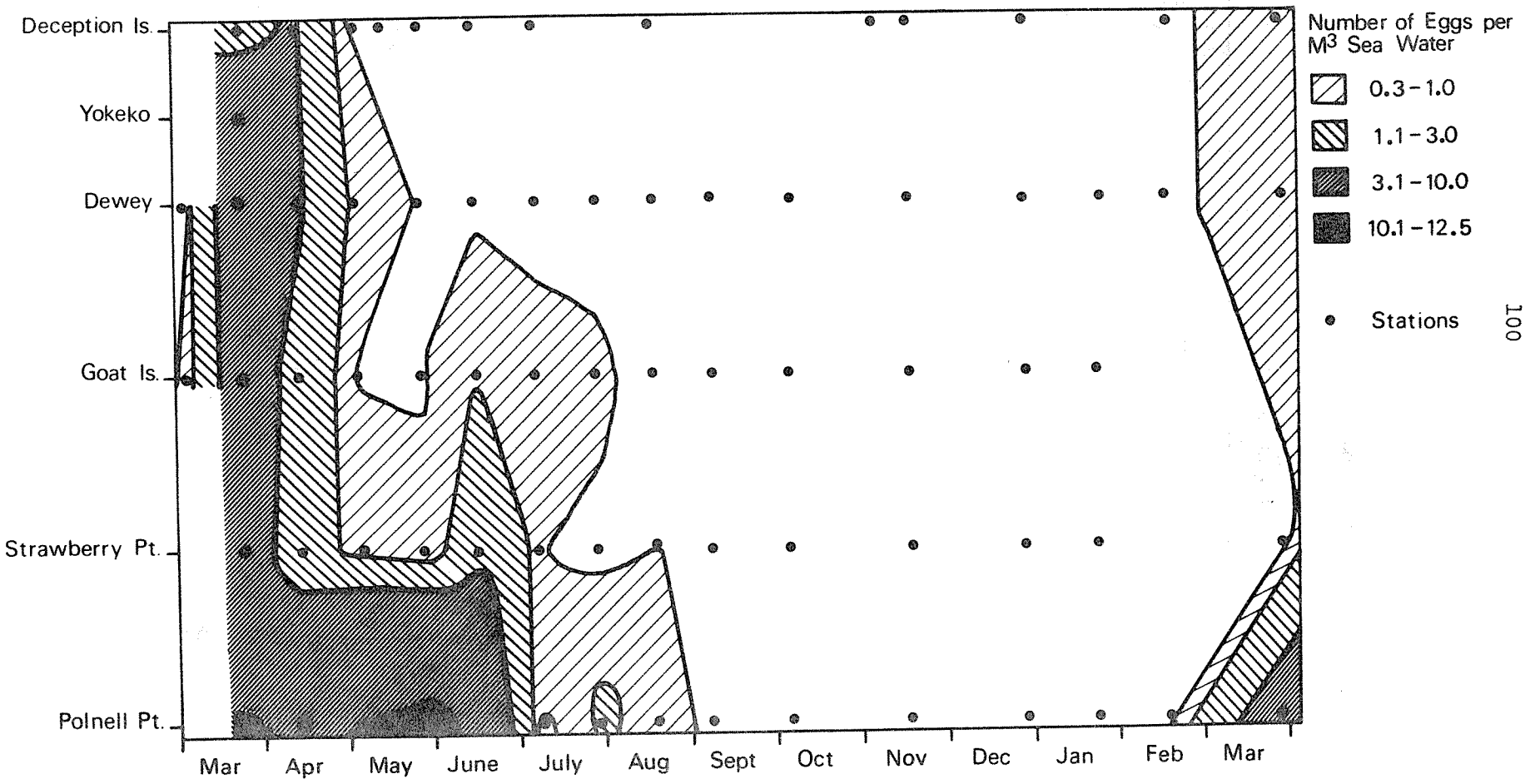


Fig. 6-4. Densities of 1-mm flatfish eggs above 5 m depth by location and date.

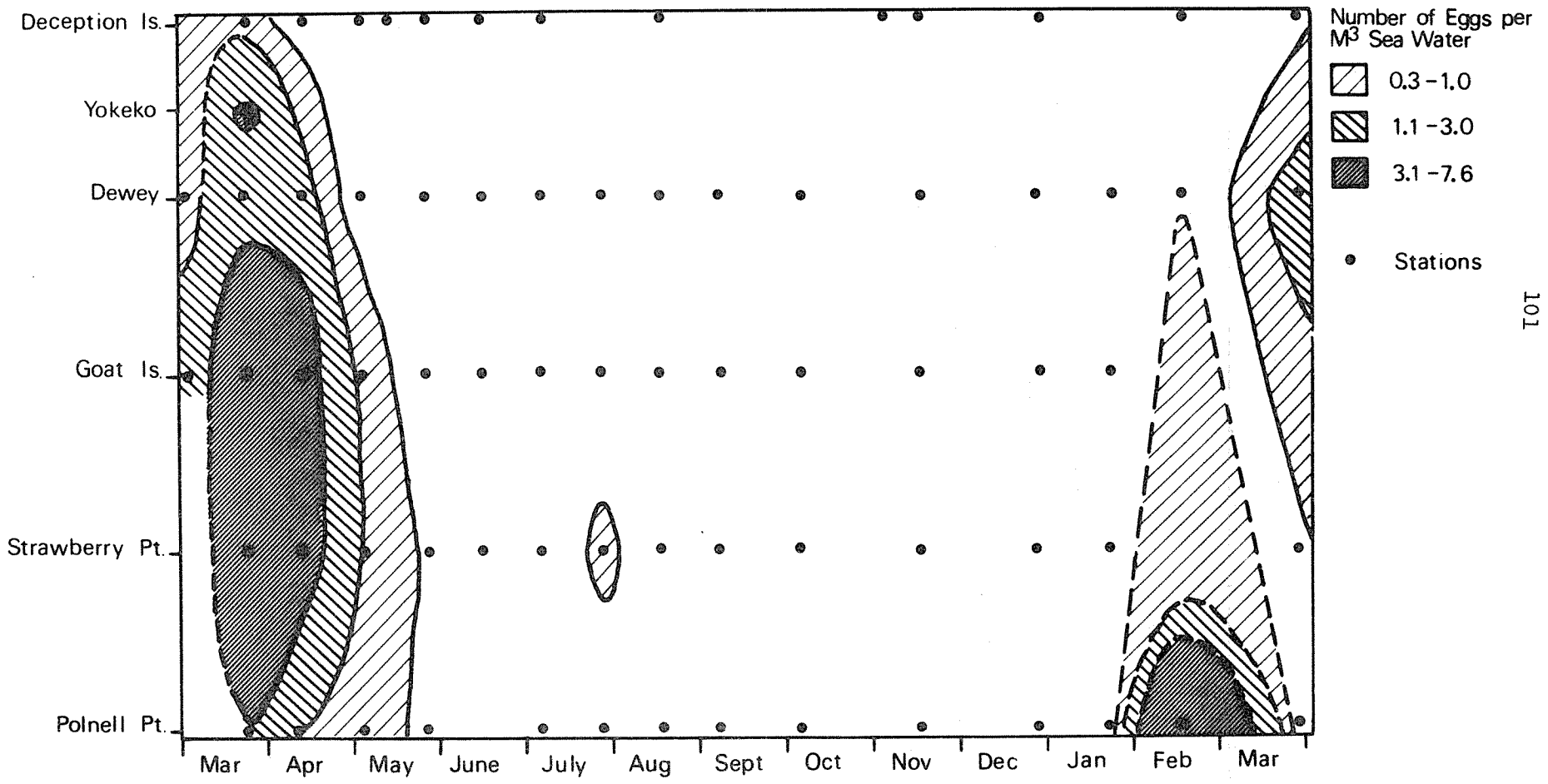


Fig. 6-5. Densities of 1-mm flatfish eggs below 5 m depth by location and date.

encountered were approximately one-day old. Thus, it appears that the sampling range did not encompass the source of the eggs after March 1971. In 1972, eggs of 16 cells or less did occur from February 24 through April 12.

The density of eggs varied cyclically with time at Yokeko on March 20 to 22, 1971 with the density at ebbtide much greater than that at flood. This variability was expected since there was a greater concentration of eggs inside Deception Pass than outside. However, it is important to establish that the differences were found statistically significant (.01) by a Kruskal-Wallis test (Table 6-9) (Bradley, 1968); which would establish a net outflow of eggs and constant replacement from inside the Pass. In the test, the 72 individual hauls through the total water column were separated according to the time of current change into eight (Fig. 6-6) successive sampling periods. The densities of eggs/m^3 for the individual tows were ranked for the test statistic. It was assumed that sampling was random, the population was infinite, and that no two densities were the same.

Age determination of some of the eggs captured at Yokeko showed differences in age composition of the samples with tidal change. Eggs captured during floodtide were generally older than eggs captured during ebbtide. Freshly spawned eggs began to appear in the samples 3 hr after the current began to ebb. Current meters deployed by the Department of Oceanography indicated a maximum ebb velocity during this sampling period of 160 cm/sec and a mean of about 120 cm/sec in the pass off the west end of Hope Island. Water moving at this rate would travel about 13 to 17 km in 3 hr. Back-calculating in the opposite direction would indicate that the freshly spawned eggs came from between Buoy 6 and Strawberry Point. There could have been no significant spawning north of Hope Island and probably none north of the tidal current node, or freshly spawned eggs would have been sampled at Yokeko within the first 2 hr of ebb. Samples taken alternately at Polnell Point and Strawberry Point in March 1971, summarized in Table 6-10, indicate that very young eggs move with the tide as it ebbs progressively farther from Strawberry Point toward Polnell Point. Thus the center of abundance and the probable origin of the very young eggs appear to be somewhere between these two locations.

Table 6-9. Results of Kruskal-Wallis test of differences in density of eggs with tidal change

i	R_i	T_i	$\bar{T}_i$	$R_i(T_i - \frac{N+1}{2})^2$
1	6	346	57.6	2688.167
2	16	354	22.12	3306.250
3	8	233	29.12	435.125
4	2	101	50.5	392.000
5	8	373	46.62	820.125
6	8	247	30.88	253.125
7	14	669	47.79	1783.144
8	10	299	29.9	435.600
				10113.536

$H = 23.090$

$\chi^2_{7df,.01} = 18.475$

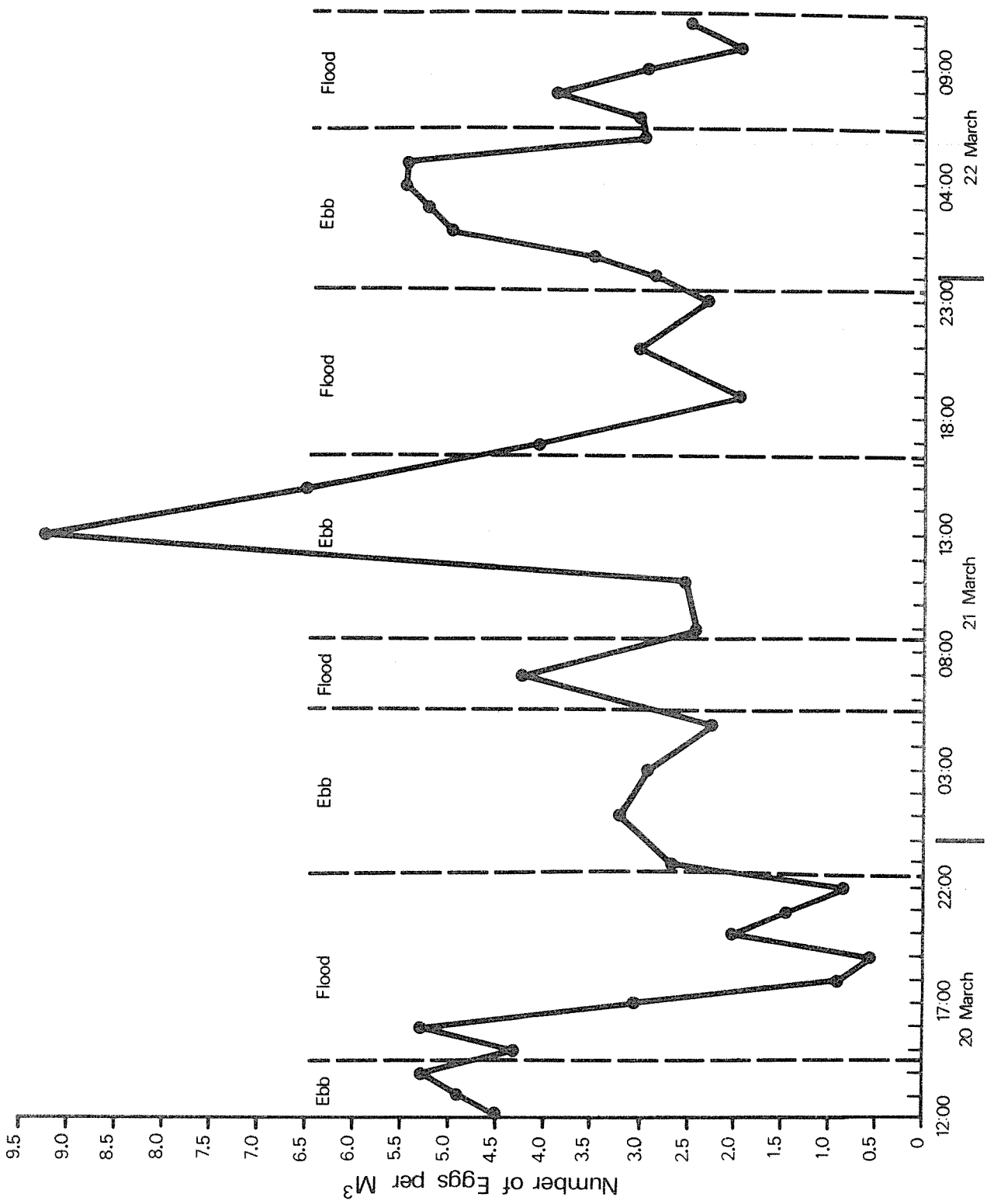


Fig. 6-6. Density of 1-mm flatfish eggs by time of sampling at Yokeko, March 20-22, 1971. Time of current change is indicated.

Table 6-10. Ratios of eggs with 16 cells or less to total eggs below 5 m by tidal stage at stations at Polnell Point and Strawberry Point in March 1971, showing shift in distribution of young eggs

Polnell Point					Strawberry Point				
Date	Time	Tidal stage,* hours until low water at Strawberry Pt.	Number of eggs below the surface with 16 cells or less divided by total eggs below the surface	Per cent of eggs below the surface with 16 cells or less	Per cent of eggs below the surface with 16 cells or less	Number of eggs below the surface with 16 cells or less divided by total eggs below the surface	Tidal stage, hours until low water at Strawberry Pt.	Time	Date
3/20/71	00:45	4-3/4	$\frac{0}{9}$	0	47	$\frac{18}{38}$	2-1/4	03:20	3/20
3/23/71	01:10	2	$\frac{4}{16}$	25	15	$\frac{4}{26}$	1/4	02:45	3/23
3/26/71	22:20	1	$\frac{16}{106}$	15	1.6	$\frac{1}{63}$	-3/4	00:05	3/27

*Tidal change calculated as 2 hr after current change in Deception Pass.

Since the eggs appear to originate south of the tidal current node during this sampling period, their movement through Skagit Bay into Rosario Strait is dependent upon current flow past the tidal current node. This flow is subject to seasonal and probably other variables and results in the dispersion of the ichthyoplankton into a biologically different area.

The importance of food and dispersion on survival have been demonstrated. Shelbourne (1957) has shown that entire spawnings of larval plaice (*Pleuronectes platessa*) starve when there is insufficient plankton on which to feed. Petrale sole (*Eopsetta jordani*) spawn in the ocean off Vancouver Island and drift to the nursery ground. The wind direction and speed determine how many young are on the nursery ground at metamorphosis and the year class strength (Alderdice and Forrester, 1971). Although the importance of dispersion and food density to ichthyoplankton has not been studied in Skagit Bay, it cannot be ignored.

6.4.6 Tidal Influence on Species Composition and Abundance

Sampling at several locations at intervals of 1 or 2 hr for 24 or 48 hr provided a means of estimating the effect of tide on the distribution of taxa, as well as the hydrographic influence on variation through the system. Samples taken at Yokeko and Dewey showed a species composition that was different on the different tides (Tables 6-11 and 6-12). Those taken nearer the tidal current node, Buoy 8 (Table 6-13), while exhibiting an orderly sequence in spite of small numbers captured are not separable by the time of tidal current change.

At Buoy 8 taxa characteristic of Polnell Point predominated over those from Dewey and occurred continuously except on two occasions, when sanddab eggs from Dewey occurred. Sanddab eggs occurred during the flood tide in each case and disappeared as the tide began to ebb.

It appears that the goby larvae originated from the Skagit Flats and were washed from the flats by the ebbing tide since they appeared in the catch at the end of ebb and then did not appear again until the end of the next ebb. They occurred during the weaker flood of the day but not during the stronger.

The sculpin *Cottus asper* occurred throughout the tidal cycle. This phenomenon would seem to indicate a constant inflow from the Skagit River since one fork of the River discharges north of Buoy 8 and the other south.

Table 6-11. Catches of each taxa at Yokeko, March 20-22, 1971, listed according to tidal stage

	First hour of ebb	Ebb	Last hour of ebb	First hour of flood	Flood	Last hour of flood	Total
Volume m^3 surface hauls	5.8	22.5	5.4	5.1	21.2	5.3	65.3
Volume m^3 deep hauls	21.5	90.7	20.3	20.1	88.0	20.6	261.2
Number of hauls, both surface and deep	6	24	6	6	24	6	72
Clupea harengus pallasi	2	5	1	2	4	2	16
Osmeridae	3	3	3	1	7	4	19
Gadidae							
Gadus-Microgadus	13	46	6	4	46	20	135
Merluccius productus		2	2		3		7
Pleuronectidae							
Lepidopsetta bilineata		4			3		7
Lyopsetta exilis egg		1					1
Lyopsetta exilis				1			1
1-mm flatfish eggs	73	593	87	112	275	53	1200
Isopsetta isolepis		6			4		10
Parophrys vetulus	2	9	2	1		1	15
Platichthys stellatus	3	10	1	4	23	3	44
Psettichthys melanostictus			1				1
Hexagrammidae							
Hexagrammos sp.		3					3
Ophiodon elongatus		1			5		5
Sebastes sp.		6			4	1	11
Cottidae							
Cottus asper					1		1
Dasycottus settiger	1						1
Leptocottus armatus		4			1		5
Myoxocephalus polyacanthocephalus						1	1
Unidentified cottid	3	9	2	1	3	2	20
Agonidae				1	1		2
Cyclopteridae		2			1		3
Ammodytes hexapterus	6	21	6		16	4	53
Pholidae	1	3	1	1			6
Stichaeidae							
Lumpenus sagitta		18	3	1	4		26
Unidentified stichaeid	1	8	2	1	6	1	19
1-mm demersal egg	4	2			21	1	28

Table 6-12. Catches of taxa at Dewey, February 17-18, 1972 and April 11-12, 1972, listed according to tidal stage of sampling

	February 17-18, 1972			April 11-12, 1972		
	Ebb	Flood	Total	Ebb	Flood	Total
Number of hauls	16	16	32	20	24	44
Total	25	34	59	160	158	318
Clupea harengus pallasi				10	5	15
Osmeridae	2		2	1	1	2
Gadidae				22	31	53
1-mm flatfish eggs				102	88	190
Parophrys vetulus		1	1	1		1
Isopsetta isolepis					1	1
Platichthys stellatus				9	5	14
Hexagrammidae						
Hexagrammos sp.	1		1			
Ophiodon elongatus				1	2	3
Sebastes sp.				3	7	10
Cottidae						
Cottus asper				1		1
Unidentified cottid		3	3	3	4	7
Cyclopteridae					1	1
Ammodytes hexapterus	18	28	46	5	6	11
Pholidae					1	1
Stichaeidae						
Lumpenus sagitta	3	1	4		1	1
Xiphister atropurpurens		1	1			
Unidentified stichaeid	1		1	1	4	5
Unidentifiable				1	1	2

Table 6-13. Total catch by station and taxon at Buoy 8 on June 15-16, 1971. Origin of the water changes with the tide and location of greatest abundance of each taxon are derived from densities at the other locations

	1-mm eggs	*Engraulis mordax* eggs	*Merluccius productus*	*Platichthys stellatus*	*Clupea harengus pallasi*	*Psettichthys melanostictus*	Gobidae	*Cottus asper*	*Citharichthys* sp. eggs	Current stage		Beginning influx of water from:
										Deception Pass	Buoy 8	
Location of greatest abundance of taxa		Polnell Point		Strawberry Pt. to Dewey	---		Skagit Flats	Skagit River	Dewey			
Time of station:												
15:04-15:36		1					2	4		Slack	E	Dewey
17:03-17:14		1	1		1		3	1		F	Slack	
19:05-19:14			1		2			1		F	F	
21:06-21:18								1	2	F	F	
23:08-23:39	4	1				1		2		E	F	Polnell
01:05-01:18	7	3		1						E	E	
03:04-03:18	4	5		1	2			3		E	E	
05:05-05:17	1	2					3			F	E	Dewey
07:07-07:18	1	2			3		3	2	2	F	F	
09:06-09:18				1			3		1	F	F	
11:04-11:14	2				1		2	1	3	E	F	Polnell
13:04-13:14	1		3		1		1	2		E	E	

6.4.7 Vertical Distribution of Townet and Plankton Net Catches

The vertical distribution by day and night of the total catch of the townet is shown in Fig. 6-7a. During the day the greatest density was at the surface and during the night it was at 18 m. The overall abundance was lowest at 9 m for day and night samples combined.

The diel vertical distribution of herring and sand lance is shown in Figs. 6-7b and 6-7c. Together, these species contributed 76 per cent of the total larvae taken and were primarily responsible for the diurnal trends in distribution of total larvae.

The vertical distribution of fish larvae in the plankton net catches at Dewey and Yokeko through the period of maximum abundance is given in Table 6-14. This table gives an estimate of densities by depth that should be considered in the placement of a cooling water intake.

6.4.8 Within-station Variation

The square root transformation was proper for deep and surface hauls at Yokeko and for deep hauls at Deception Island and Polnell Point (Fig. 6-8). The logarithmic transformation was proper for deep hauls at Dewey, Goat Island and Strawberry Point and for surface hauls at all locations except Yokeko (Figs. 6-9 and 6-10). The differences in standard deviation between stations were insignificant.

The 95 per cent confidence intervals and standard errors of the mean of a pair of hauls from the depths and locations where the logarithmic transformation was appropriate are given in Table 6-15. Where the square root transformation was appropriate the intervals are given in Table 6-16.

All methods of standardizing the catch, volume, flowmeter revolutions, and station depth produced the same variance estimates as catch per tow.

Although the variability of the plankton catches was sometimes greater than that reported in the literature (Cassie, 1968), it was generally not too great to support the conclusions reached in this study. Predominant species were presented as Ahlstrom (1968) used and they appeared to be quite invariable in dominance. Densities and numbers of 1-mm eggs per unit of sea surface were presented with contour intervals of approximately three, which is broader than the 95 per cent confidence interval in most cases. Probably the most dubious figures are those presented in Table 6-10.

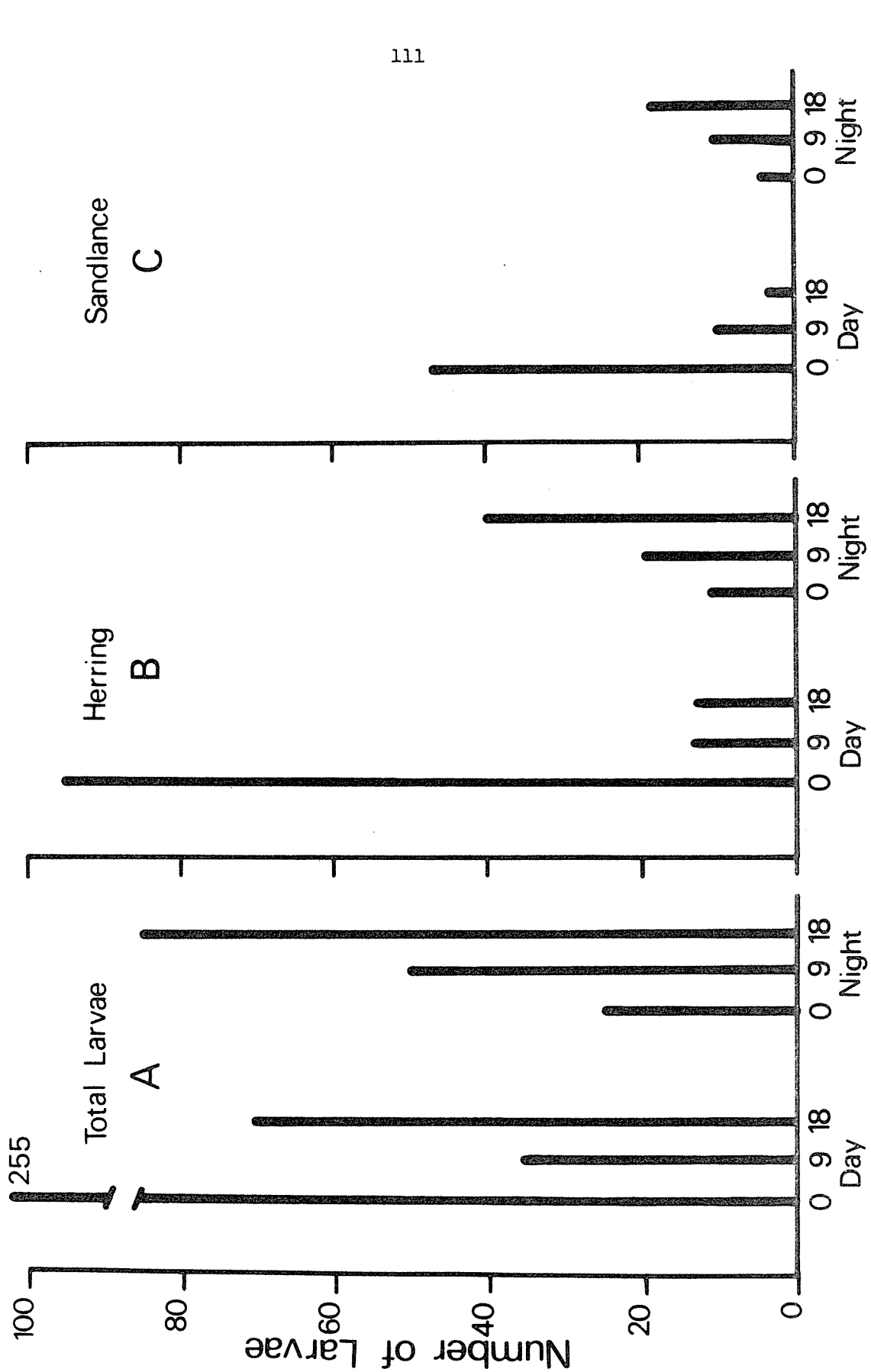


Fig. 6-7. Catches of total larvae, herring, and sand lance per townet haul by depth, day versus night.

Table 6-14. Densities of fish larvae captured in the plankton net by depth at Dewey and Yokeko

Date	Density, number/m^3			Number of samples	
	Total water column	Surface 5 m	Below 5 m	Surface 5 m	Total water column
19-27 March 71	1.31	1.80	1.22	6	6
19-27 March 71*	1.22	1.41	1.16	72	72
13-15 April 71	1.63	1.25	1.69	4	4
4-5 May 71	.362	1.88	.106	4	4
27-28 May 71	.254	0	.312	4	4
15-18 June 71	.698	.714	.695	8	8
11-12 April 72	.781	.295	.885	22	22

*Taken at Yokeko.

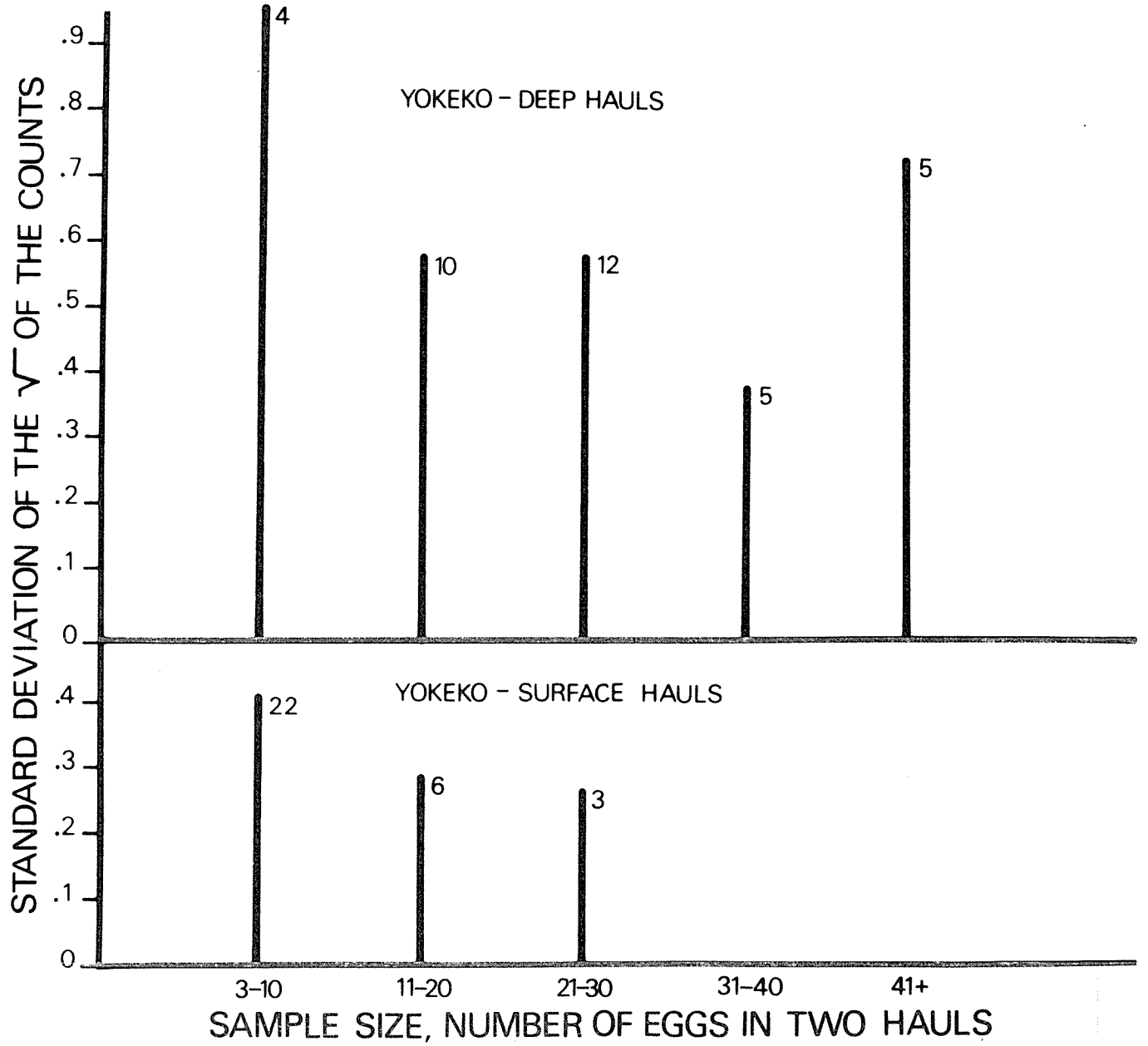


Fig. 6-8. Standard deviation of square root transformed egg counts by sample size class, surface and deep hauls, Yokeko.

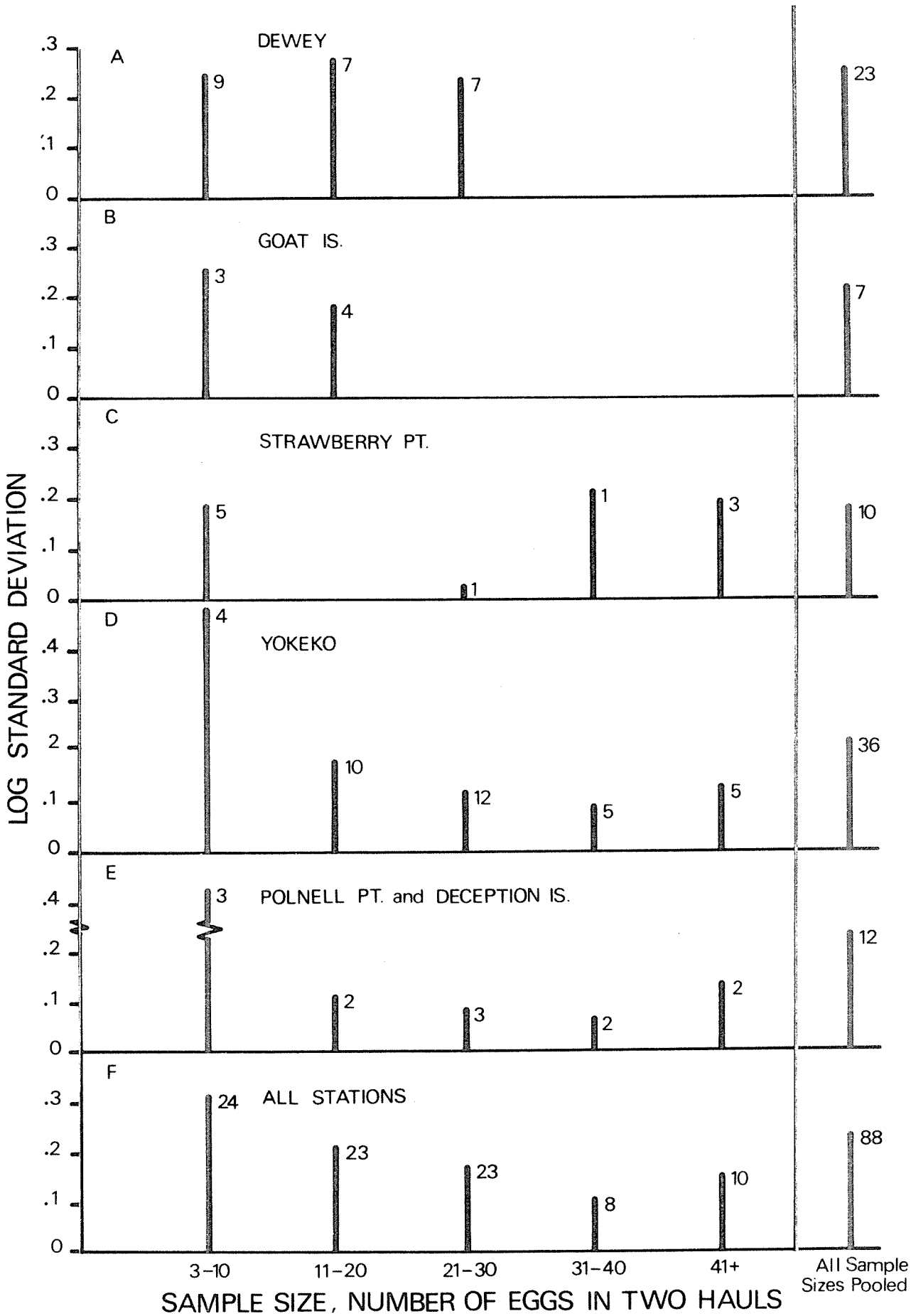


Fig. 6-9. Standard deviation of logarithmic-transformed egg counts by sample size class, hauls through total water column, all areas.

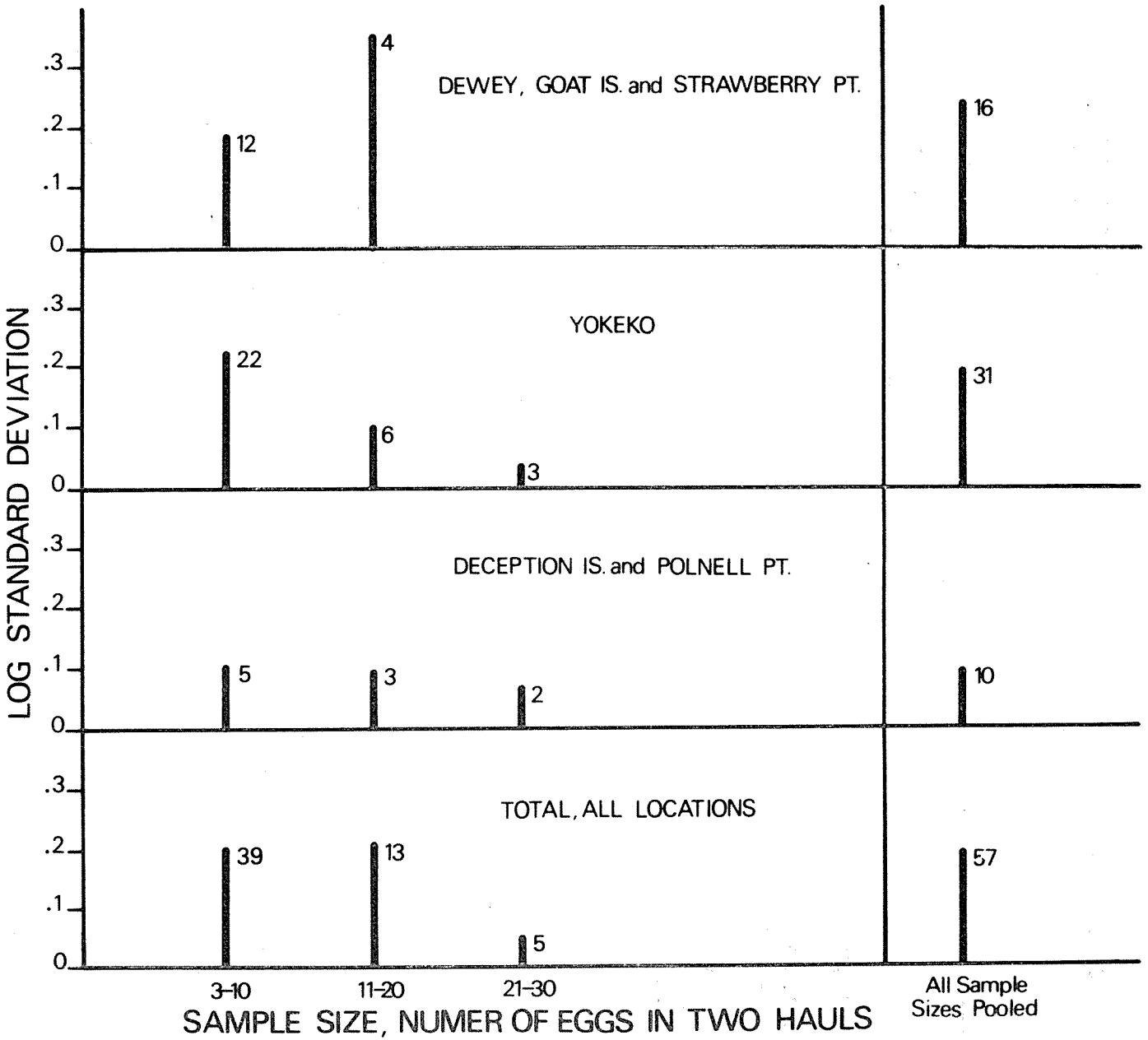


Fig. 6-10. Standard deviation of logarithmic-transformed egg counts by sample size class, surface hauls, all areas.

Table 6-15. Confidence intervals and standard errors of the mean numbers of 1-mm eggs per haul for all depths, all locations. The confidence interval for 2 tows is the mean multiplied and divided by the tabled value

	95 per cent Confidence interval	50 per cent Standard error of mean
Surface 5 m	1.882	1.239
Total water column (deep)	2.064	1.281
Below 5 m (surface-deep)	2.624	1.388

Table 6-16. Confidence intervals and standard errors of the mean numbers of 1-mm eggs per haul, assuming two hauls were used in the estimate, for deep samples at Yokeko from square root-transformed data. The tabled values are the upper limits divided by the means and the means divided by the lower limits. These data should be compared with the logarithmic calculations in Table 6-15.

Per cent confidence	Limit	Number of eggs in a pair of samples 3-10	11-20	21-30	31-40	40 +
50	Upper	1.644	1.208	1.167	1.100	1.161
	Lower	1.940	1.232	1.182	1.105	1.175
95	Upper	4.223	1.738	1.569	1.400	1.664
	Lower	∞	2.152	1.791	1.498	1.984

The number of eggs with 16 cells or less was quite small, but the consistency of the trend lends additional support to the validity of the observations.

6.5 SUMMARY AND CONCLUSIONS

During the 16-month study from January 1971 to April 1972, 897 plankton samples were taken from the waters in and adjacent to Skagit Bay. These yielded 4,602 ichthyoplankton specimens, which were separated into seven fish egg and 43 larval taxa. The maximum abundance in March and April 1971 and 1972 and minimum abundance in November and December 1971 were reflected in both the number of individuals and frequency of positive tows.

Ten taxa contributed 88.3 per cent of the catch. Listed in order of decreasing numbers captured they were: 1-mm flatfish eggs, cod larvae (*Gadus-Microgadus*), Pacific sand lance (*Ammodytes hexapterus*) larvae, starry flounder (*Platichthys stellatus*) larvae, Pacific herring (*Clupea harengus pallasi*) larvae, northern anchovy (*Engraulis mordax*) eggs, Pacific hake (*Merluccius productus*) eggs and larvae, smelt (*Osmeridae*) larvae, sanddab (*Citharichthys* sp.) eggs, and rockfish (*Sebastes* sp.) larvae.

Samples were taken with large and small townets of 3-mm mesh from March 31 through May 26 and June 4 through September 29, 1971, respectively. The catches of these nets were predominantly Pacific herring and Pacific sand lance in the large net and Pacific herring and threespine stickleback, in the small net.

The plankton catch in Skagit Bay may be separated into three general groups, those most abundant within the Bay, those present but more abundant in Saratoga Passage, and those present but more abundant in Rosario Strait. Entrainment problems would probably be unique for each group. The input of plankton from Saratoga Passage is subject to seasonal variation and undoubtedly annual variation. The input of plankton from Rosario Strait would probably be more regular and emanates from a considerably larger source (i.e., Straits of Juan de Fuca). The taxa that have their greatest abundance within Skagit Bay, Pacific herring, smelt, sanddab, prickly sculpin, gobies, snake prickleback, unidentified stichaeids and sand lance, would be most vulnerable to entrainment.

The greatest densities of larvae are on the surface in the daytime and nearer the bottom at night; the best depth for an intake would be at a depth intermediate in the water column. The depth of minimum abundance was 9 m in the townet samples.

In order to minimize entrainment of ichthyoplankton, it would appear desirable to place an intake where it would obtain water entering Skagit Bay from Rosario Strait. In this way, entrainment of species most abundant locally would be minimized, and water containing the least ichthyoplankton would be utilized. The optimum intake location is below the surface but above 18 m and within the area of rapid current flow.

7.0 INTERTIDAL ECOLOGY

by

J. P. Houghton

7.1 INTRODUCTION

Despite the considerable volume of literature on the acute thermal tolerances, Q_{10} values, and temperature-dependent growth parameters of various intertidal species, the current state of knowledge does not allow accurate prediction of the effects of low-level "thermal enrichment" on a natural ecosystem. Measurement of the effect of any slight alteration in a metabolic activity on the growth, abundance, and distribution of species within the community is tremendously difficult. Perhaps the best means of attaining, in the near future, the capability of predicting even the less subtle of the effects of artificial increases in the ambient temperature on a dynamic marine ecosystem lies in securing adequate quantitative baseline information and documenting changes occurring over a sufficient period of time.

In this study, therefore, an effort was made to describe baseline conditions within the existing intertidal communities of Kiket Island prior to construction and operation of the nuclear power plant. It was hoped that quantitative measurements of a number of population parameters would make it possible in the future to determine whether changes were statistically significant. The primary objectives were: (1) establishment of as complete a species list of the intertidal macroflora and macrofauna of the Island as possible; (2) qualitative and quantitative description of the abundance and distribution of these macroorganisms and seasonal variations therein, and (3) investigation of the age and growth characteristics of the native littleneck clam (*Protothaca staminea*) at various locations about the Island. The secondary objectives were: (1) collection of ecological data on invertebrate species found, (2) estimation of age and growth characteristics of edible bivalves less abundant than *P. staminea*, and (3) comparison of zonation patterns at Kiket Island with those reported in the literature for other Eastern Pacific areas.

7.2 REVIEW OF THE LITERATURE

Marine biologists have devoted considerable effort to the study of intertidal organisms and communities, probably because of the almost universal appeal of the seashore and the ease of access relative to other marine communities.

Much of the early work in intertidal ecology was concerned with qualitative descriptions of zonation patterns on rocky shores and attempts to explain the causes of their existence. This large body of literature is summarized excellently by Lewis (1963), Doty (1957), and Southward (1958) and will not be further detailed here except to mention the more significant studies concerning the west coast of North America.

The entire San Juan Islands intertidal and subtidal region, including the area around Kiket Island, was divided on the basis of major faunal components into large regions, or "biomes," by Shelford et al. (1935). These biomes could be subdivided into "associations" and "fasciations" to account for local variations (e.g., zones). Hewatt (1937) and Rigg and Miller (1949) conducted studies of zonation of plants and animals in Monterey Bay and near Neah Bay, Washington, respectively. More recently, Stephenson and Stephenson (1961*a* and *b*) worked with zonation on cliffs and beaches near Nanaimo on Vancouver Island and fitted their results into a "universal scheme" of intertidal zonation. In the Northern Pacific, Nybakken (1969) has described the zonation in a semiprotected bay on Kodiak Island. Several authors have reported on various aspects of zonation across the broad rocky intertidal benches at Amchitka Island in the Aleutians (Lebednik, Weinmann, and Norris, 1971; O'Clair and Chew, 1971).

Zonation on intertidal substrata other than rock has been largely ignored by ecologists, possibly because the zones are usually less obvious and the procurement of data is more laborious. In the case of sandy beaches, the organisms involved are frequently small ones whose taxonomies are imperfectly known. On cobble or gravel beaches, the distribution of epifauna and flora may be patchy and present confusing patterns. Hedgpeth (1957) has reviewed the scanty literature concerning zonation on sandy beaches. Lengthy studies of the organisms in the estuarine sand and mud of Elkhorn Slough was reported by MacGinitie (1935). Nybakken (1969) compared zonation on the cobble beaches at Kodiak Island with that on the rock cliffs there and elsewhere. Ricketts and Calvin (1968) included all of these substrata as well as rock in their detailed descriptions of the organisms of various intertidal levels and habitats.

Quantitative evaluations of intertidal zonation patterns have been somewhat lacking also; those of Hewatt (1937) and Nybakken (1969) provide notable exceptions.

Some emphasis in recent years has been directed toward the use of the intertidal as a convenient location for the study of the effects of competition and predation on the distribution of organisms and on community structure (Connell, 1961*a* and *b*, 1970; Dayton, 1971; Harger, 1972; Paine, 1966, 1969; Palmisano, 1972 personal communication).

Autecological studies of a variety of intertidal animals have been presented by Ricketts and Calvin (1968) for the area from California to Alaska, by MacGinitie and MacGinitie (1949) principally for species found in Elkhorn Slough, and by Horn (1932) for some invertebrates of Lonetree Point, adjacent to Kiket Island in Skagit Bay, Washington. Ricketts and Calvin (1968) also provide references to a number of smaller-scaled studies dealing with one or a few species.

Although considerable study has been devoted to the ecology and taxonomy of intertidal invertebrates in the vicinity of the Friday Harbor Laboratories on San Juan Island, very little research of a general nature within Puget Sound proper has been published. Lie (1968) has made significant progress in reporting on the subtidal benthic infauna of the Sound, but even that is just a beginning.

Information on the ecology of pelecypods of recreational or commercial importance in Puget Sound has been reported by several authors, some working in the Sound but most elsewhere, especially in British Columbia. Fraser and Smith (1928*a* and *b*) and Fraser (1931) provided some notes on the ecology of the butter clam, *Saxidomus giganteus*, the native littlneck, *Protothaca staminea*, and the cockle, *Clinocardium nuttalli*, in British Columbian waters. Quayle (1943, 1952, 1964, 1969) has worked extensively with several commercial species in British Columbia, including the Pacific oyster, *Crassostrea gigas*, the native littleneck, the Japanese littleneck, *Venerupis japonica*, and others. Much work has been done on the softshell clam *Mya arenaria* but most has been on the East Coast (Newcombe, 1936; Swan, 1952; Ayers, 1956). The ecology and production portential of the geoduck, *Panope generosa*, in Puget Sound was investigated by Anderson (1970). Ohba (1959) in Japan and Nosho and Chew (1972)

in Puget Sound have followed the setting and early growth of the Japanese littleneck.

Frizzel (1931) sketched the life history of the native littleneck, *P. staminea*, and looked at variations among populations from several locations around Puget Sound. More recently, Schmidt and Warme (1969) described the population characteristics of the species in Mugu Lagoon, California. In both of these studies, as well as in Fraser and Smith's (1928b) research, age was ascertained from concentric growth rings on the external surface of the shell. Several other authors have considered these rings to be annular on various species of clams, for example: Newcombe (1936) on *Mya arenaria*, Weymouth (1923) on the Pismo clam, *Tivela stultorum*, Quayle (1952) on *Venerupis pullastra*, and Fraser and Smith (1928a) on the butter clam, *S. giganteus*. More recently, Negus (1966) used annular rings in the shells of several species of freshwater unionid mussels to evaluate growth and production. Ansell (1961) aged *Venus striatula* using annular checks and found considerable variability of growth rate within a year class at a given location.

Hirschhorn (1962) used tagging, annular rings, and size frequency distributions to calculate the mortality rate and von Bertalanffy growth equation for the razor clam (*Siliqua patula*) on the Oregon coast. Hancock (1965) derived a von Bertalanffy growth equation from a Ford-Walford plot of annular rings in *Cardium edule* and compared his results with equations derived from tagged clams.

Use of this technique of age determination is not universally reliable, however, especially in areas of slight yearly variation in temperature, food, etc. Ohba (1959) found growth rings on *V. japonica* in Southern Japan to be confusing. In a review of various attempts to use rings for age determination of clams, Quayle (1952) found more successes than failures but wisely recommends verification of the technique in each local population to be studied. Further reviews of applications of these procedures are found in Haskin (1954) and Segerstråle (1960).

7.3 MATERIALS AND METHODS

7.3.1 General

Marine biologists frequently find that the long-established sampling techniques of terrestrial plant ecologists are readily adaptable to intertidal studies. The relative immobility of the majority of intertidal macro-organisms lends itself to this kind of approach and of the organisms encountered in this study, only the amphipods were active enough to pose difficulties in assessment.

The pelagic and planktonic organisms in the water that covers the intertidal for varying periods of time daily certainly have a profound influence on the energy budget and the ecology of intertidal organisms. However, the importance of these organisms could not be measured by the methods described below.

During September 1969, a datum line was established around Kiket Island by surveyors of Seattle City Light at +9 ft above mean sea level (MSL). For the region of this study, approximate conversion from this reference (MSL) to the reference in common usage on tide tables, that of mean lower low water (MLLW) involves merely the addition of +6 ft to the MSL value. Unless otherwise noted, all tidal levels referred to in this paper were referenced to this +9 ft datum (relative to MSL) by surveying with a standard transit and leveling rod.

Other materials utilized included:

standard field collecting accessories (forceps, jars, polybags, labels, etc.)

A set of two nested aluminum-framed screens approximately 40 x 40 cm in area by 13 cm deep with stainless steel mesh having 19- and 7-mm square openings

a wash tub and buckets for sieving

shovels

0.25 m^2 and 0.1 m^2 tubular aluminum quadrats

circular plastic 0.1 m^2 subsampling ring

43.7 cm^2 by 10 cm deep stainless hand-coring device

100-ft vinyl tapemeasure

0.25 m^2 open-ended steel frame 30 cm deep

Rollei 3.5 twin lens reflex camera

Ektachrome EX-120 film
Honeywell strobonar electronic flash
Mayer's Underwater Photogrammetric System Frame (MUPS)
dial calipers
balance, and
rope, slings, and carabiners for rock climbing.

7.3.2 General Collections

Nonsystematic collecting was done throughout the study period on tides as low as -3.8 ft (Relative to MLLW) for the purpose of gathering organisms that were missed in the systematic sampling. The effort was concentrated on localized habitats and lower tidal levels that could not be covered by systematic sampling. Specimens from the systematic sampling and from general collecting were identified to species, if possible, and the identifications were verified by taxonomic specialists, if available.

7.3.3 Beach Transects

From the datum line established by surveyors from the Seattle City Light Department, eight transects across the intertidal were surveyed in September 1969 (Fig. 7-1). These transects were located to cover all bottom types around the Island and to include areas expected to be affected by plant construction and operation, as well as those expected to be relatively unaffected. Each transect was marked at 2-ft intervals of tidal level with steel stakes or "PK" nails depending on the substrate.

At each level, a 100-ft tape was laid perpendicular to the transect following the beach contour and three samples were taken at randomly selected distances along the contour. The random selection of multiple sample plots at each level permitted the statistical analysis of population densities at each level and, in effect, extended each line transect to a band 200 ft wide. At each location the sample area was delineated by a 0.25-m^2 tubular aluminum quadrat or, in soft substrata, by an inserted steel quadrat of the same area and 30 cm in depth. In soft sands and mud this device prevented cave-ins and insured a uniform sample size. At each quadrat the percentage of cover

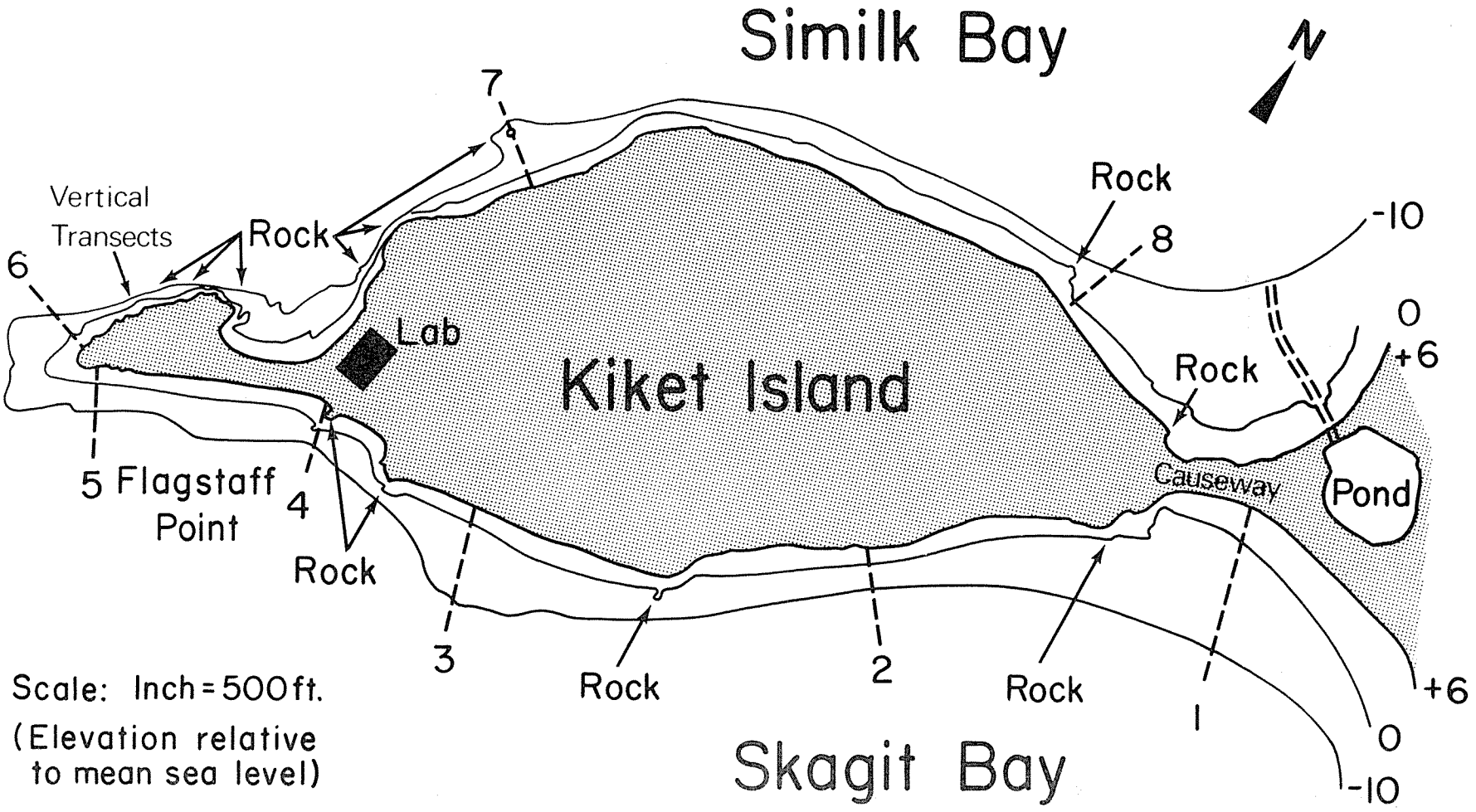


Fig. 7-1. Map of Kiket Island intertidal study area, indicating transects and local landmarks.

of algae was estimated first. The abundance of the various species of surface fauna was then determined. Finally, the entire quadrat was excavated to a depth of 30 cm wherever the substrate allowed. All of the material was washed through two nested screens with mesh sizes of 20 mm and 7 mm.

The residue of unsievable material was then hand sorted and all macroorganisms were removed and either counted or returned to the laboratory for preservation in 10% formalin. Because of the coarseness and irregular size distribution of sediment on most beach areas studied, this procedure frequently required in excess of one hour for single quadrat. The 30-cm depth was found to be deep enough to include all larger macrofauna except the deep burrowing *Callianassa, Upogebia, Tresus* and a few polychaetes. When burrows of these organisms were encountered an effort was made to dig them out. If this effort was unsuccessful, their presence was noted, and in the case of *Upogebia*, (the most abundant of the deep burrowers), the occurrence of a tunnel or tunnels was taken to signify the presence of one individual.

The sampling efficiency was very high, approaching 100 per cent for firm-bodied animals of sizes down to about 10 mm. Animals of this size and smaller might slip sideways through the screen if they became oriented to the diagonal of an opening. Sampling of larger soft-bodied animals was also efficient, except for some very active animals such as *Nephtys caeca*, which frequently wriggled through. Large numbers of small polychaetes, ophiuroids, sipunculids, etc. were also taken but quantitative efficiency was considerably lower.

In the initial series of samples taken during the winter of 1969-70, very numerous and small organisms, such as barnacles, littorine snails, amphipods, and polychaetes, were not sampled quantitatively but only noted as present or abundant. Starting with the series of samples taken in the summer of 1970, we subsampled all of these organisms either by the use of a randomly placed 0.01-m^2 ring or by counting individuals in a fraction of the total quadrat judged to represent "average" conditions of abundance for the species in question. All figures of abundance were then corrected to the full 0.25 m^2 area by simple multiplication. Although there were statistical errors involved in these procedures, it was felt that they were justified by the necessity of dealing with very abundant organisms as well as by the large numbers themselves. Thus, in these cases the numbers amounted to order of magnitude estimates. Also starting in the summer of 1970, we modified this

procedure further to extend the size range of infaunal organisms sampled down to a more commonly accepted limit for macrofauna of 1 mm. Before digging each quadrat, we took a randomly placed subsample with a hand-held coring device. This corer was a stainless steel cylinder 43.7 cm^2 in area and 10 cm deep with a handle and a thumb-operated vent hole resembling a miniature "clam gun." Where cobble or gravel prevented full insertion of the corer, the same volume subsample was taken by hand digging of an equal area to 10 cm in depth. We took each of these subsamples whole to the laboratory for washing with freshwater to avoid contamination with planktonic forms. After sieving on a No. 18 Tyler screen, we hand sorted the residue to remove all organisms. The depth of 10 cm appeared sufficient to include a vast majority of the smaller macrofauna.

Counts of larger macrofauna taken in the core were added directly to the counts from the whole quadrat. Counts of smaller macrofauna not normally taken in the larger screens were corrected to 0.25 m^2 by the area ratio. For abundant and evenly distributed species, the errors involved in this estimate probably are not great. For the rarer or aggregated of the small organisms, the error is certainly significant, as with the subsampled epifauna.

The initial sampling scheme was to take three samples at each 2-ft interval of tidal level at each transect for four sampling periods from the winter of 1969-70 to the summer of 1971. This procedure would result in 12 samples at each 2-ft level on each transect. However, after one year of sampling, it was decided to increase the effort on two transects to include samples at each foot of tidal level to improve the accuracy of the description of the vertical distributions of the organisms. Transects 2 and 8, typical of the south and north sides of the Island respectively, were chosen. Because of limited sampling time and resources, it was necessary to discontinue sampling on transect 3, which was very similar in substrate to transect 2. Transect 5, which crossed the unique flat rocky bench on the south side of Flagstaff Point, was not comparable in bottom type to other transects and sampling was also discontinued here. It was felt that the data from 1969-70 would be sufficient to describe the biota of this limited area.

Sampling in the winter series extended from mid-November to early May, and all summer sampling was completed from late June to early August.

7.3.4 Description of Seasonal Fluctuations in Algae

Color photographs of fixed 0.25-m^2 plots at each 2-ft tide level on each beach transect were taken from April 1970 through July 1972, for the purpose of assessing seasonal fluctuations in algal cover. Mayer's Underwater Photogrammetric System (MUPS) (Mayer, 1969 unpublished MS) was used; thus, all pictures were taken from a constant height and with a constant reference length included. Photographs were taken monthly from April through September and at least bimonthly during the rest of the year. Each photograph was positioned by alignment of the upper left-hand corner of the MUPS frame in contact with the surveyed steel stake or nail marking the level.

A Rollei 3.5 twin-lense reflex camera was used with Ektachrome EX 120 film. A shutter speed of 1/500th of a second with a Honeywell Strobonar electronic strobe provided constant illumination under daytime or nighttime conditions.

7.3.5 Vertical Transects

To accurately establish the vertical range of species and to describe zonation patterns on the rocky cliffs that comprise a varying proportion of the intertidal on the north side of the Island, we established line transects on the north side of Flagstaff Point (Fig. 7-1). On these transects, 0.1-m^2 quadrats were examined at each foot of tidal level from +6 ft to -4 ft. The base of the cliff ranged from about -4.5 ft to -5 ft and thus precluded procurement of lower samples. A single line of PK nails was positioned by a survey at each foot of tidal level. To provide a statistical basis for comparisons of densities, we sampled four parallel transects in 1970 and 1971 during the months of July through September. The location of these transects was measured at 4, 8, and 12 ft from the surveyed nails along the cliff face by means of a hand level and a rigid measuring rod so that proper height would be insured. The 1970 samples were positioned at left of the 0-, 4-, 8-, and 12-ft locations and the 1971 samples to the right (facing the water) so that resampling of areas disturbed in the previous year would be avoided. Because of the near vertical nature of the cliff in this area, we sampled most of the upper levels either from a boat on a rising or falling tide or suspended from the cliff on ropes using standard mountaineering techniques.

In each quadrat, the percentage of cover by each species of algae was first estimated and then all animals present were couted, if possible. Although most of the many nooks and crevices formed by the bases of the larger barnacles and the fractures of the rock were diligently searched and probed with forceps, it is probable that some smaller organisms living therein were missed. Very numerous species, such as the smaller barnacles and littorine snails, were subsampled by use of a circular plastic ring 0.01 m^2 in area.

This procedure is a modification of that of Nybakken (1969), who used adjacent 0.25-m^2 quadrats in studying similar vertical cliffs on Kodiak Island, Alaska. The smaller quadrat size used at Kiket Island was found necessary for delineation of sharp density changes and description of the range limits of species on the vertical cliff without the taking of laborious notes as to the location of individuals within the quadrat. Because of irregularities in the cliff profile, it was felt that referencing each sample to a surveyed mark at each foot of tidal level would permit a more consistent sampling pattern than the belt-transect technique used by Nybakken (1969). With this fixed location sampling pattern, four samples were taken at each of the 11 levels sampled in each summer. Thus, direct comparisons and statistical combinations of data from each level were possible

7.3.6 Age and Growth Studies

To clarify the nature of the rings laid down in the shell sculpture of *P. staminea*, we dug a series of samples each month from the end of May to the first of November 1972. All samples were taken from the same population of clams at the -4-ft level ($\pm$ 1 ft) in front of the laboratory. Measurements of the number of growth rings, length of the last growth ring, and total length of each clam were taken for computation of the month-by-month growth increment (ΔL) since the last ring. A portion of the May, June, and August samples was marked and, along with some umarked clams, were planted in fixed plots in the same area so that various disturbance checks, if any, could be identified. Marking consisted either of a series of "/'s" or "X's" filed on the side or a "V" notch, 1 to 2 mm deep in the ventral margin of the clam. All replanted samples were collected on November 5, 1972 for final analysis.

To investigate the age and growth at various locations and tidal levels, we made the following measurements on most of the edible bivalves taken in the

beach transects: length (maximum anterior to posterior distance), height (maximum dorsal to ventral distance), thickness (maximum side to side distance), age (as determined by the number of rings), wet weight, and length of each annular ring. We took sufficient numbers of *P. staminea, S. giganteus, Mya arenaria,* and *C. nuttalli* to make growth estimates meaningful. A few of the clams taken could not be measured for one or more of the above values because of damage from digging or inadvertent loss of the shells. Whenever possible, wet weights were taken live with the shell closed and patted damp-dry with paper towels. The majority of clams could not be measured, however, util after preservation in buffered 10% formaldehyde. Their weights (damp-dryed) were corrected in all analyses by factors computed on measurements of weight loss in clams first weighed live and then after varying periods of preservation.

The measurements of annular rings were in most cases rather straightforward in *P. staminea* up to 6 or 7 years old. Beyond this age often confusing patterns reduced the accuracy of these measurements. This age was somewhat greater in *S. giganteus* and less in *M. arenaria*. The shorter-lived *C. nuttalli* all had clearly distinguishable growth lines.

Another problem encountered in the measurement of growth rings and the assignment of an age value to them resulted from the first growth ring having been obscured by the erosion of the umbonal region on many of the larger *P. staminea*. The following guidelines were adopted for standardization of the designation of age values to all clams, eroded or not. The largest second ring that was observed on any younger *P. staminea* (where all rings were clearly visible) with a first ring of under 3 mm was about 13 mm. Also, the largest first ring observed (with no rings in the 1-3 mm range) was about 13 mm. Therefore, all larger clams with the first visible ring greater than 13 mm were assumed to have actually had a first ring of 3 mm or greater. Frequently, we could make this ring visible by lightly sanding the umbonal region with fine sandpaper. When this failed, an arbitrary value of 3.0 mm was assigned. Smaller specimens of *P. staminea* frequently had visible rings from 2-3 mm in length, with a second ring of from 7 to 12 mm. Others had their first ring in the same size range. Because of the uncertainty involved in older clams with eroded umbones and first visible ring in this range, all rings under 3 mm were

not recorded. Thus, a number of clams, probably those from late summer spawning, were actually one year older than recorded. The size of all *P. staminea* at the first winter was therefore somewhat arbitrarily set at from 3 to 13 mm. We could have avoided this compromise only by throwing out all measurements from clams with any erosion of the umbones, which constitued a substantial proportion of the population.

Specimens of *S. giganteus*, although frequently much larger than *P. staminea*, were generally less eroded; and it was felt that all rings greater than 3 mm could be seen. None under this length were counted.

7.3.7 Data Processing and Statistical Procedures

The vast quantity of distributional data from the vertical and beach transects, as well as the monthly percentages of algal cover from the periodic photography, was compiled and summarized by the use of locally prepared programs for the CDC 6400 digital computer. Several diversity indices were calculated by means of other locally prepared programs from data obtained in random quadrat sampling on the beach transects: for the fauna of each quadrat, for each group of three quadrats at a given level and season, and for progressively pooled results from the 9 quadrats surveyed in the summer 1970 through summer 1971 sampling periods, as suggested by Pielou (1966). Data from the first sampling series (winter 1969-70) were omitted from the pool because counts were not made on very abundant species and no cores were taken. Comparisons were made with calculations excluding counts of highly abundant but very small species based on core samples and excluding obvious dominant species (e.g., *Balanus glandula*).

Diversities on the vertical transects were calculated for individual samples, for pooled samples at a given level for each summer, and for the pooled samples of both years at each level.

The indices calculated were:

a) Species richness (Margalef, 1968)

$$D = \frac{S-1}{\ln N}$$

b) Number of moves (Fager, 1972)

$$NM = 1 - \frac{N(S+1) - 2\,\Sigma R_i\, n_i}{(N-S)(S-1)}$$

c) Shannon-Wiener (Pielou, 1966)

$$(H') = SW = -\Sigma \frac{n_i}{N} \ln \frac{n_i}{N}$$

d) Scaled Shannon-Wiener (Fager, 1972)

$$CORSW - \frac{SW-A}{\ln S-A}$$

e) Eveness factor (Pielou, 1966)

$$J = \frac{SW}{\ln S}$$

where: n_i = number of individuals in the i^{th} species,

N = total number of individuals,

S = total number of species present,

R_i = rank of the i^{th} species (most abundant species R=1),

$$A = \ln N - \frac{(N-S+1)}{N} \ln (N-S+1)$$

= minimum value of SW for given S and N.

Means and variances for the several measurements of over 2,000 clams and breakdown by transects, levels, years, etc. were computed by means of the Statistical Package for the Social Sciences (SPSS) series of programs. Various length-weight regressions were computed by the same means. The month by month growth rate of *P. staminea* as a function of age was evaluated through the X-TAB PLOTONE program. The locally prepared FRD-312 Weighted Linear Regression Program was used in a Ford-Walford type plot to obtain parameters for the van Bertalanffy growth equations in the method summarized by Gulland (1969) Derivation of survivorship equations were also made with the FRD-312 program.

Analyses of variance and other statistical tests were applied through the techniques described by Steel and Torrie (1960).

Unless otherwise noted, 95% confidence intervals of the means are given for the various parameters.

Figures for the area of beach between certain contours, used in calculations of total standing crop, were derived by the use of a planimeter on a large-scale (1" = 100 ft) contour map. The area considered as part of Kiket Island was from transect 1 (Fig. 7-1) around the Island to a line normal to the beach contours directly across the causeway from transect 1.

7.4 RESULTS

7.4.1 Physical Description of the Intertidal

The intertidal area surrounding Kiket Island was composed of a wide variety of bottom types and sediments. A broad, gently sloping beach lay south of the spit in the vicinity of transect 1 (Fig. 7-1), consisting of clean sand with medium-size (1-2.5 cm) gravel at the +3-ft level and grading into relatively pure sand from +1 ft to -3 ft. Sand with increasing clay and silt content was found from -3 to -5 ft, with mud and eel grass (*Zostera marina*) at -7 ft. The area around the rocky point west of transect 1 had small (5-10 cm) and medium (10-15 cm) cobble at the upper tidal levels with smaller gravel and coarse sand in the interstices. At the lower tidal levels, from 0 ft to -4 ft, larger cobble (to 25 cm) and boulders up to a meter or more in diameter were encountered. At about the -5.5-ft level, there was a transition from cobble with sand to predominantly sand with a few cobble. This rather narrow sandy

belt became increasingly silty at lower levels and, at the -8-ft level, was muddy with some surface cobble. This pattern of small cobble, larger cobble, sand with cobble, and mud with cobble continued west along the south side of the Island to transect 4 with minor variations and with two interruptions by narrow rock outcroppings (indicated on Fig. 7-1). These outcroppings extended out and down to about mean sea level, below which the pattern described resumed. At transect 3, there was an especially broad shelf at about the -8-ft level with a large, shallow tidal pool, exposed only on the lowest tides. The shelf was basically solid gravel and rock covered with several centimeters of silt and mud with numerous large boulders scattered about. West from transect 3 to transect 4, the cobble decreased gradually in size.

Between transect 4 and transect 5 from the high-water mark to about the -4-ft level was a uniform stretch of well-sorted, medium-size gravel. Below this level was a band of silty sand with small cobble merging into mud with cobble and *Zostera*. From transect 5 through the tip of Flagstaff Point, an irregular, rocky shelf extended from the high-tide line to the -3-ft level. Below this level to -6 ft, there was sand with some small cobble, and at -7 ft, silty sand, cobble, and eel grass.

Along the north side of the Island, except at a few small coves, steep rock cliffs continued well down into the intertidal. Beneath these cliffs the beach consisted of mixed silty sand and gravel with varying amounts of cobble and broken shell. From the -6 ft to the -8-ft level, the silt and clay content increased but there was no band of sand, as occurred on the south side at about -6 ft.

On the north side of Flagstaff Point including the vertical transects, nearly vertical cliffs dropped to -4 or -6 ft before intersecting the beach. In front of the laboratory (Fig. 7-1) from the high-water mark to about -5 ft arced a fairly broad beach of coarse sand, shell, and small gravel (to 1 cm). Below this level increasing silt was present, grading into mud and eel grass. North of the laboratory, the rock cliffs began again and, on the point between the laboratory and transect 7, extended below the lowest low tide (about -9.8 ft), the only location on the Island where this occurred. At transect 7 a large, jutting rock outcropping was connected to the beach by a narrow sand-spit at the -5-ft level. From transect 7 east around the north side of the Island to the last rock outcropping, the base of the cliffs varied from -4 ft

to +4 ft. North of the causeway, between transect 8 and the pond, there was a broad beach, similar to that south of the causeway but with much coarser sediments, On the north side at upper tidal levels, the sediments contained considerable small and medium cobble. In the midtidal range, coarse sand, broken shell, and small gravel occurred, grading into a broad mudflat at about -8 ft.

7.4.2 General Composition of the Flora and Fauna

The total of at least 251 macroscopic species and types of intertidal animals and 51 species of plant were encountered in the several phases of intertidal studies at Kiket Island. Complete distributional data along with ecological and taxonomic notes for each species are presented in Appendix 7.A. A breakdown of the number of species in each major taxon is given in Table 7-1.

Table 7-1. Number of species per taxon for all intertidal sampling.

Taxon	No. of Species	Taxon	No. of Species
Miscellaneous Invertebrata	11	Mollusca	(55)
Coelenterata	6	Amphineura	9
Nemertinea	14+	Lamellibranchia	20
Annelida	(87)	Gastropoda	26
Polychaeta	84		
Oligochaeta	3	Total Invertebrata	242+
Echinodermata	13		
Crustacea	(56)	Chordata	8
Cirripedia	4		
Chelifera	1	Plants	51
Isopoda	10		
Amphipoda	18		
Decapoda	23	Total species	302+

The number of species found on any one transect generally increased with decreasing tide level, as would be expected on any transect across a gradient of decreasing environmental stress, in this case exposure to desiccation (Figs. 7-2 and 7-3). In some areas species richness diminished with decreasing heterogeneity or stability of the substrate. For example, along most of the south side of the Island there were more species at the -3 or -4-ft level in

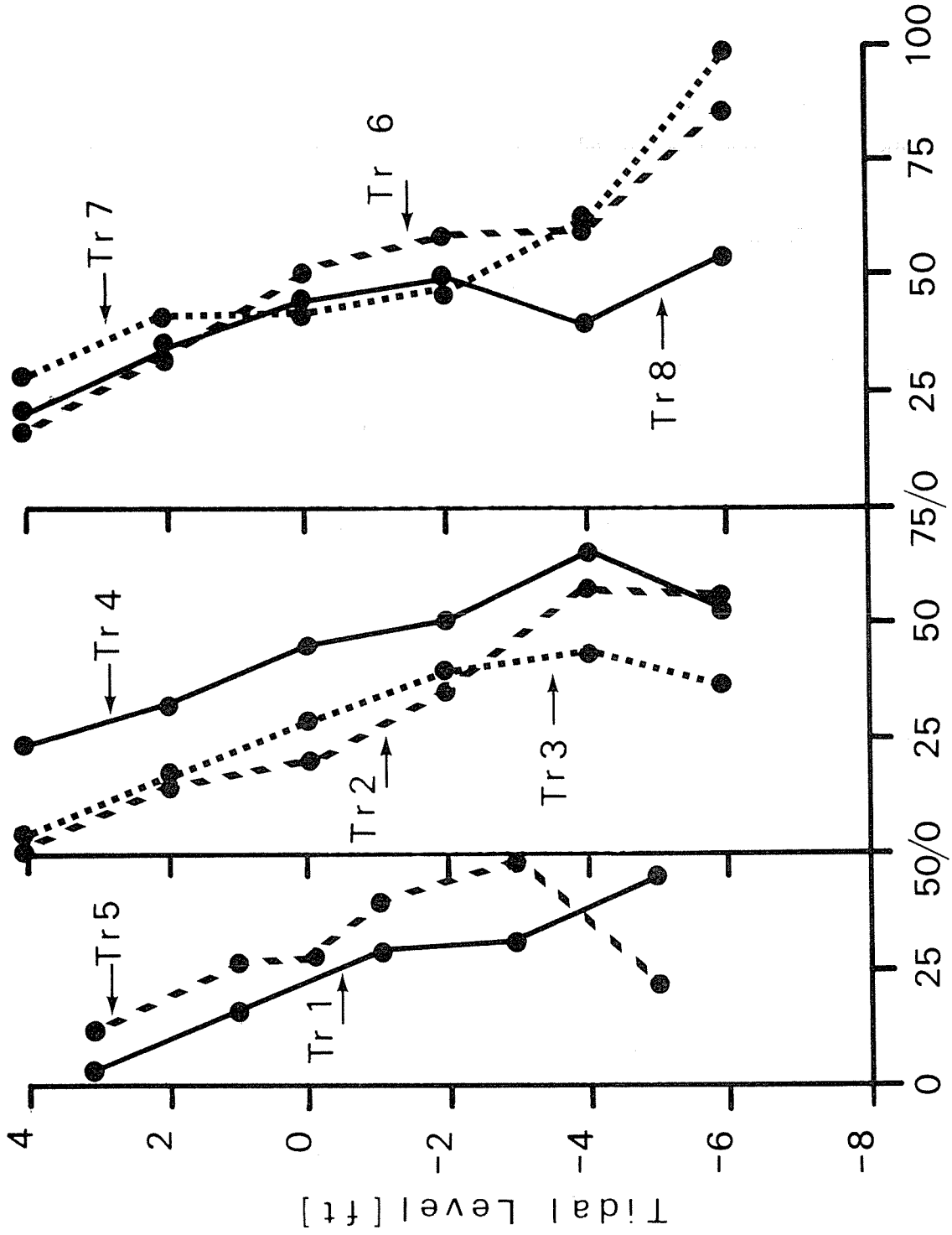


Fig. 7-2. Vertical distribution of number of invertebrate species from all beach transect sampling. Transects 3 and 5 based on 6, 0.25 m^2 quadrats. All others based on 12.

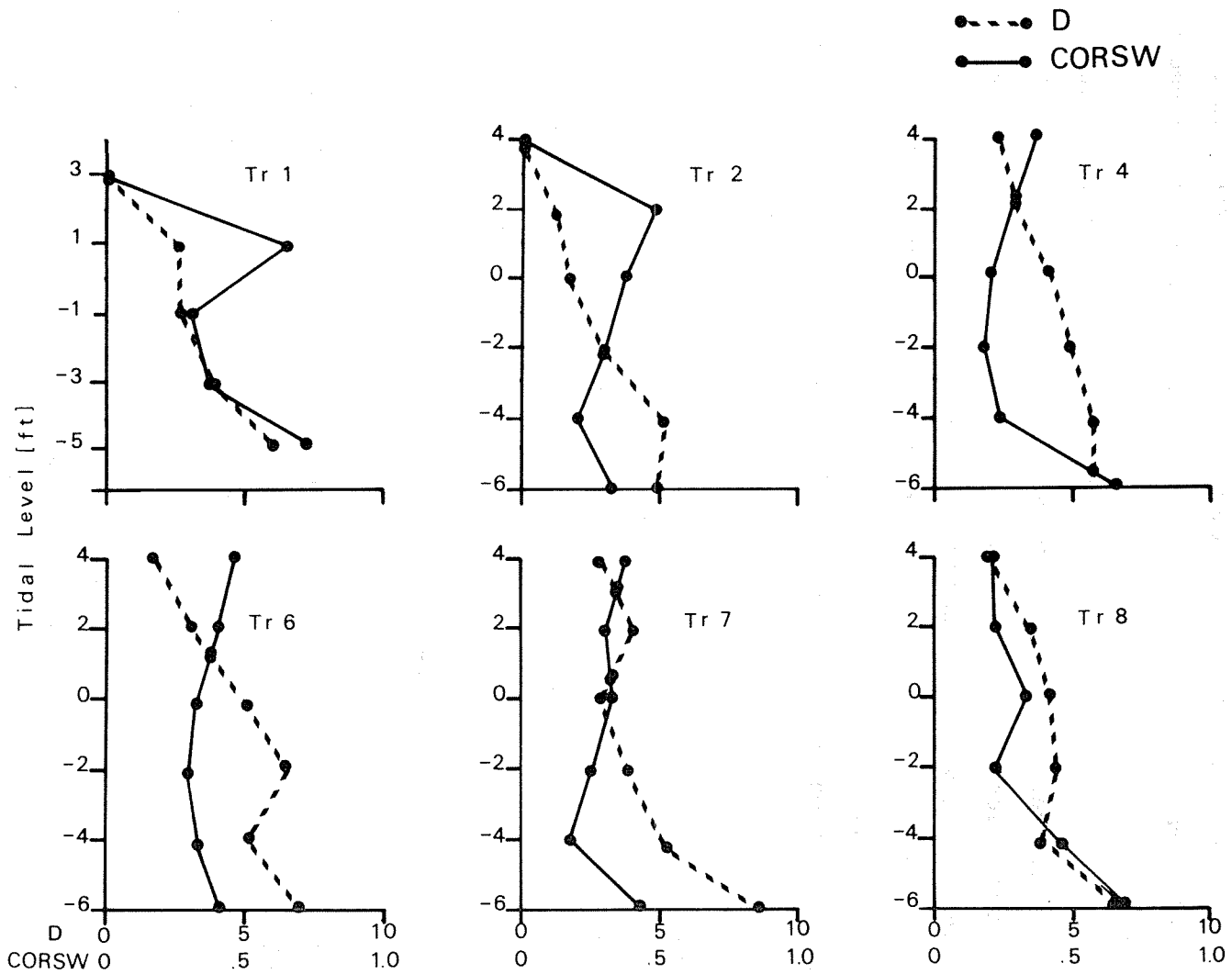


Fig. 7-3. Calculated diversity indices (D, CORSW) on 6 transects. Counts from core subsamples excluded. Nine samples (summer 1970 - summer 1971) progressively pooled.

stable cobble or rock than at the -6-ft level (-5 on transect 5) in sand with sparse cobble. This diminution is due to a reduction in substrate suitable for infauna. The trend of increasing diversity of infauna continued through the lower level. On transect 1, where there were no major changes in the sandy beach and epifauna were largely absent, species richness continued to increase through the lowest level sampled. Because of the rocky cliffs encountered on the north side at higher tidal levels, there were far more species than at equivalent levels on the south side. Even in the limited areas of the north side where cliffs did not occur (e.g., +4 ft on transect 8) there were significantly more organisms on and under the cobble substrate, the increase reflecting the diminished severity of desiccation. On the beaches below the cliffs on the north side species richness was higher at any given level than on the south side and increased steadily with decreasing tide level since the transition to a sandy substrate did not occur. The only exceptions were some areas in the vicinity of the -4 to -6-ft levels on transect 8 composed of pea gravel and shell with few cobble, which tended to be unstable in the occasional heavy wave action and had a very poor fauna.

The greatest number of animal species found at any level (98) and in any one sample (49) was at transect 7 at -6 ft in very silty mixed sediments with some cobble of various sizes.

7.4.3 Zonation on the Beach Transects

7.4.3.1 South side

The sloping cobble beach that comprised the majority of the south side of Kiket Island (transects 2, 3, and 4) displayed a pattern of three more-or-less distinct bands characterized by the relative abundance of certain obvious organisms (Figs. 7-4 and 7-5). Boundaries between bands were seldom as sharp as is typical of the rocky intertidal, showing rather gradual transition and varying in tidal level laterally because of the influence of biological, physical, and hydrographic factors. These bands will be briefly described here as "zones" according to the nomenclature of Stephenson and Stephenson (1961*a*), and later compared with zonation patterns of other Western American intertidal studies.

The uppermost of these, the "supralittoral fringe," extended from the high-tide mark to about the +3-ft level and was distinguished by the lack of

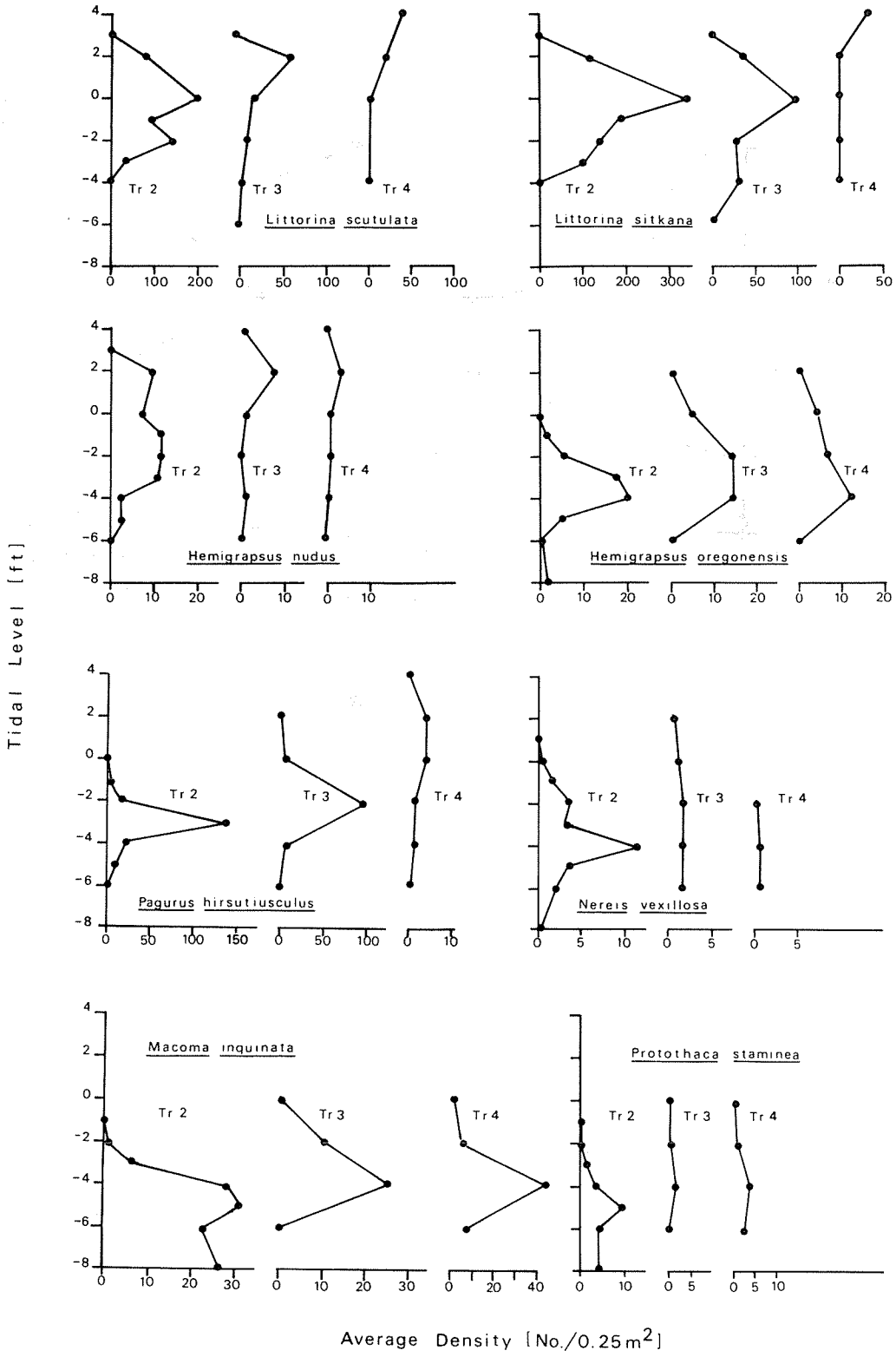


Fig. 7-4. Average density of selected invertebrate species from 2 years' sampling on 3 transects on the south side of Kiket Island. Transect 3 based on 6 samples. All others based on 12.

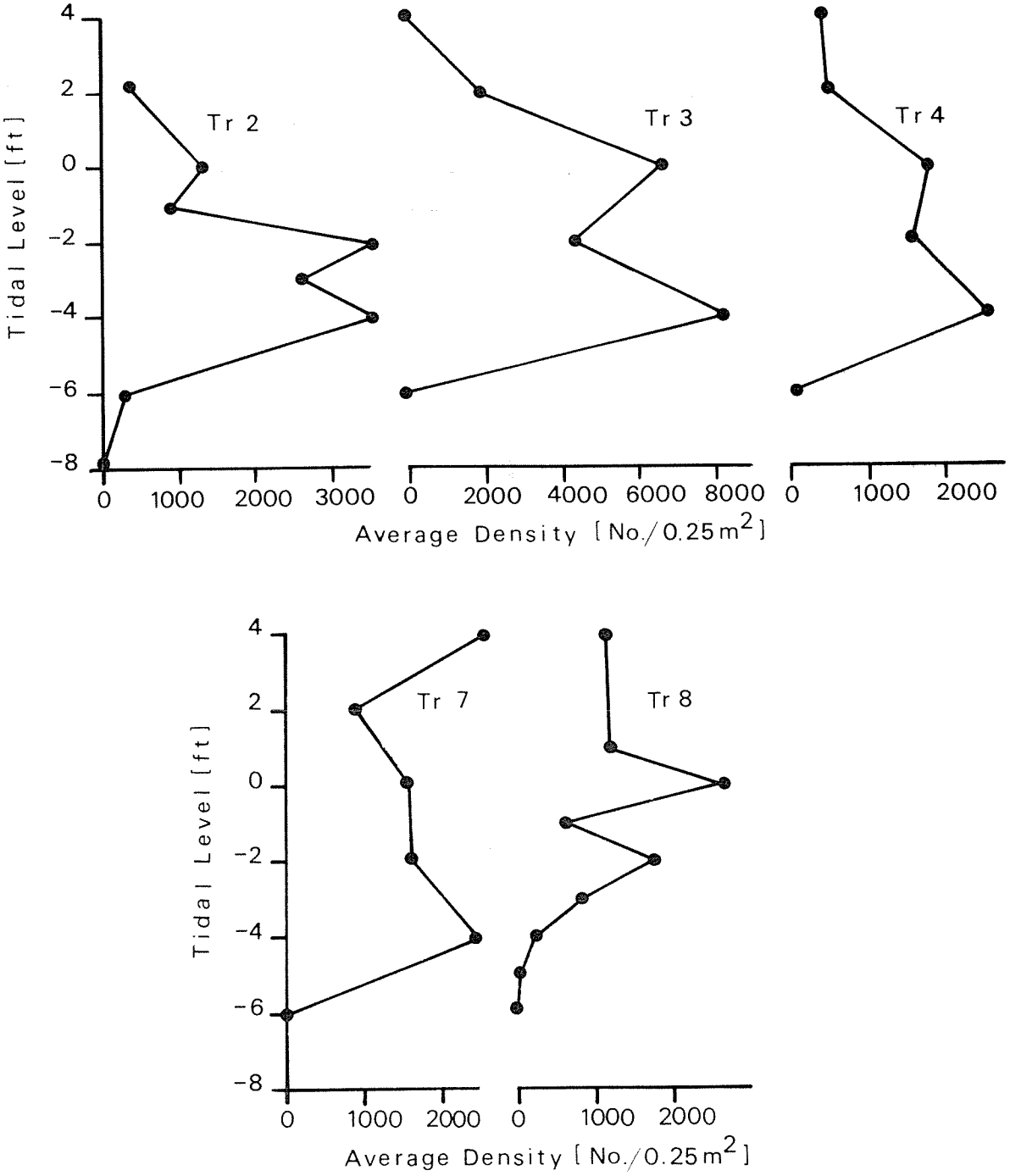


Fig. 7-5. Average density of *Balanus glandula* from 2 years' sampling on 5 transects. Transect 3 based on 3 samples. All others based on 9.

attached organisms. It consisted of essentially barren rock, cobble, or gravel with a few littorine snails (*Littorina* spp.) and limpets (*Acmaea persona*). The most abundant organisms were the amphipod *Orchestia traskiana* and an unidentified oligochaete. Both were numerous in the detritus and drift algae at the high-tide line. Infauna was absent in the cleaner sediments underlying stable areas of larger cobble. Where a small cobble or gravel surface permitted currents and wave action to introduce significant detritus to varying depths, a few species thrived including *O. traskiana*, the oligochaete, an unidentified centipede, and the tiny gastropod, *Assiminea*(?).

At approximately the +3-ft level, the barnacle zone began; significant numbers of *Balanus glandula* were established on the shaded sides (north and northeast) of larger cobble and boulders. The predominance of *B. glandula* in terms of numbers and biomass of all organisms extended to below the -5-ft level through what may be considered to be three subzones distinguished primarily on the diversity of the infauna. To avoid adding to the already overburdened nomenclature of intertidal zonation, we termed these the upper, middle, and lower barnacle zones following Stephenson and Stephenson (1949).

The upper barnacle zone, from +3 to mean sea level, had no appreciable attached algae other than the encrusting red, *Hildenbrandia prototypus*. In addition to *B. glandula*, the smaller cirripede *Chthamalus dalli* reached its highest density in this zone although it never approached the numbers of the larger form. The littorines, the amphipod *Hyale plumulosus*, and the shore crab, *Hemigrapsus nudus*, were highly abundant. Typical organisms associated with barnacles were also present, including several nemerteans, syllids, and the small anemone *Diadumene luciae* (?). Infauna was still largely lacking, but another oligochaete and the pile worm, *Nereis vexillosa*, were occasionally found in moderate numbers. Diversities calculated for this level (Fig. 7-3) were higher than those for the lower barnacle zones because *B. glandula* had not yet attained the overwhelming abundance it did at lower zones.

A patchy dark band of the brown algae *Fucus distichus* extending approximately from mean sea level to the -2-ft level delineated the middle barnacle zone. The lower tidal level and the additional protection from drying offered by the fronds of *Fucus* permitted the survival of a richer fauna than that of the upper barnacle zone although the predominant animals here were the same ones noted in the upper zone. Several species occurring infrequently at higher

levels were found in increased numbers, including the mussel, *Mytilus edulis* (Fig. 7-6), the pill bug *Gnorimosphaeroma oregonensis*, the shore crab *H. oregonensis*, and the hermit crab, *Pagurus hirsutiusculus* (Fig. 7-4). The richness of the infauna was also substantially greater because of the first appearance of a number of polychaetes, the blue mud shrimp, *Upogebia pugettensis*, and several clams. These remained a major component of this community throughout the lower levels.

The lower barnacle zone extended from the lower limit of significant *Fucus* growth (about -2 ft) down to the vicinity of mean lower low water (-6 ft). For much of the year this zone appeared little different from the two above it and indeed the epifauna was again comprised mostly of *B. glandula* and included in abundance many of the same species that were characteristic of the middle barnacle zone. During the spring and summer months this entire area was almost completely covered with a mat of green alga *Ulva lactuca*, which provided an efficient screen against desiccation by the summer sun during the daytime low tides (*see* Fig. 7-17). This additional protection and the still shorter periods of emersion resulted in a marked increase in species richness, particularly in the subsurface fauna. Many new species of polychaetes and bivalves accounted for much of this increase. *N. vexillosa* and *Notomastus tenuis* of the polychaetes and *Mytilus edulis, Macoma inquinata* and *Protothaca staminea* of the bivalves were most abundant. Despite the increase in species richness (Fig. 7-3), the vast numbers of *B. glandula* which covered almost the entire exposed surface of cobble in this zone (e.g., transect 2 -4 ft) actually caused a decrease in diversity indices (NM, SW, CORSW). Values calculated on invertebrate counts with *B. glandula* excluded showed a steady increase from 0-ft to the -4-ft level (Fig. 7-7). There was a severe reduction through the lower barnacle zone in several species that were important in the middle and upper barnacle zone: *H. nudus, H. plumulosus*, and both species of *Littorina*.

The lowest zone on the south side of the Island began at about mean lower low water (-6 ft) with the transition from cobble to a sand-and-mud substrate with a few cobble. Although *Zostera marina* was scanty at -6 ft, it was the most conspicuous organism of this zone, and was continuous subtidally. It was therefore called the *Zostera* zone. Since this zone did not have the

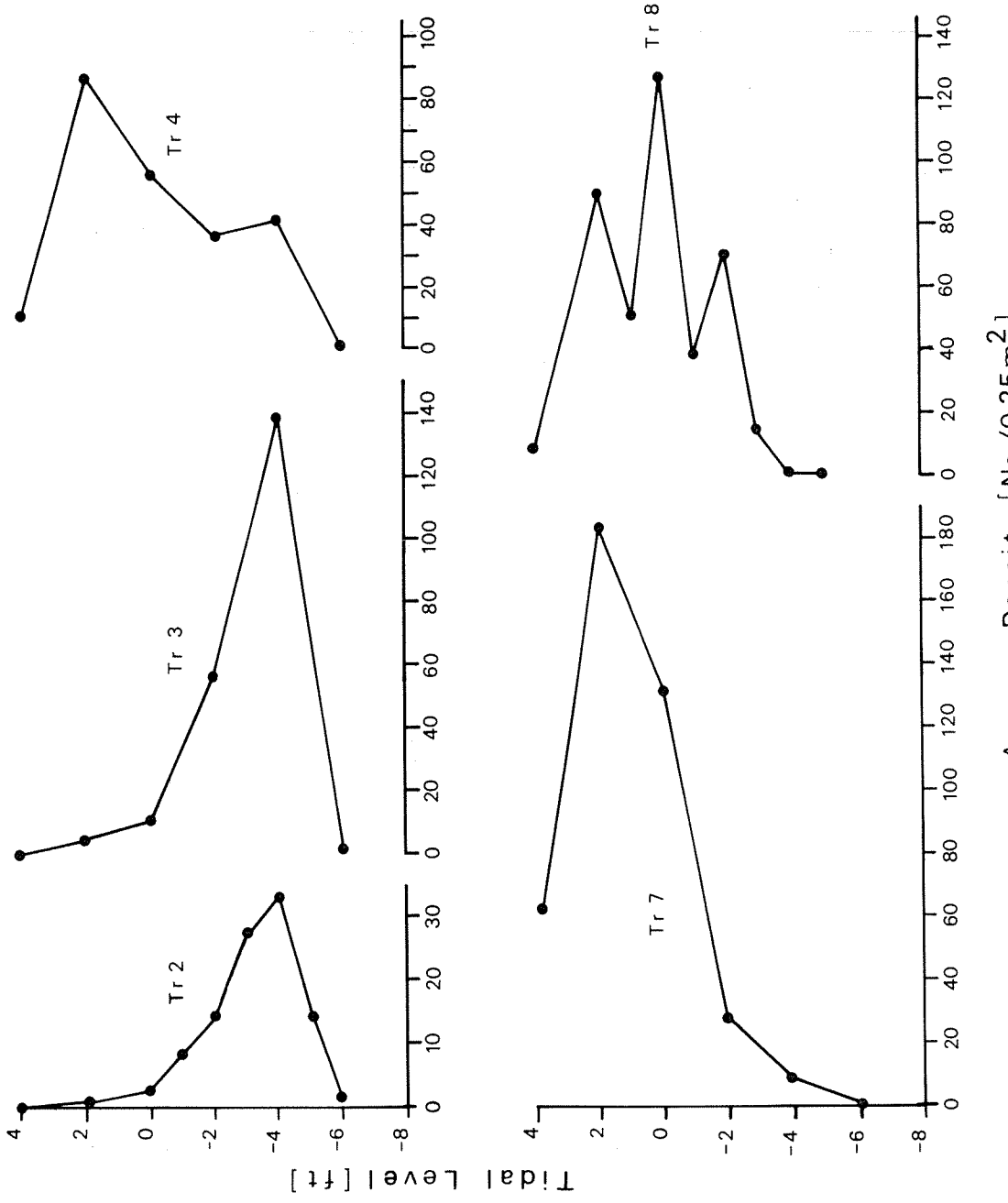


Fig. 7-6. Average density of *Mytilus edulis* from 2 years' sampling on 5 transects. Transect 3 is based on 6 samples. All others are based on 12 samples.

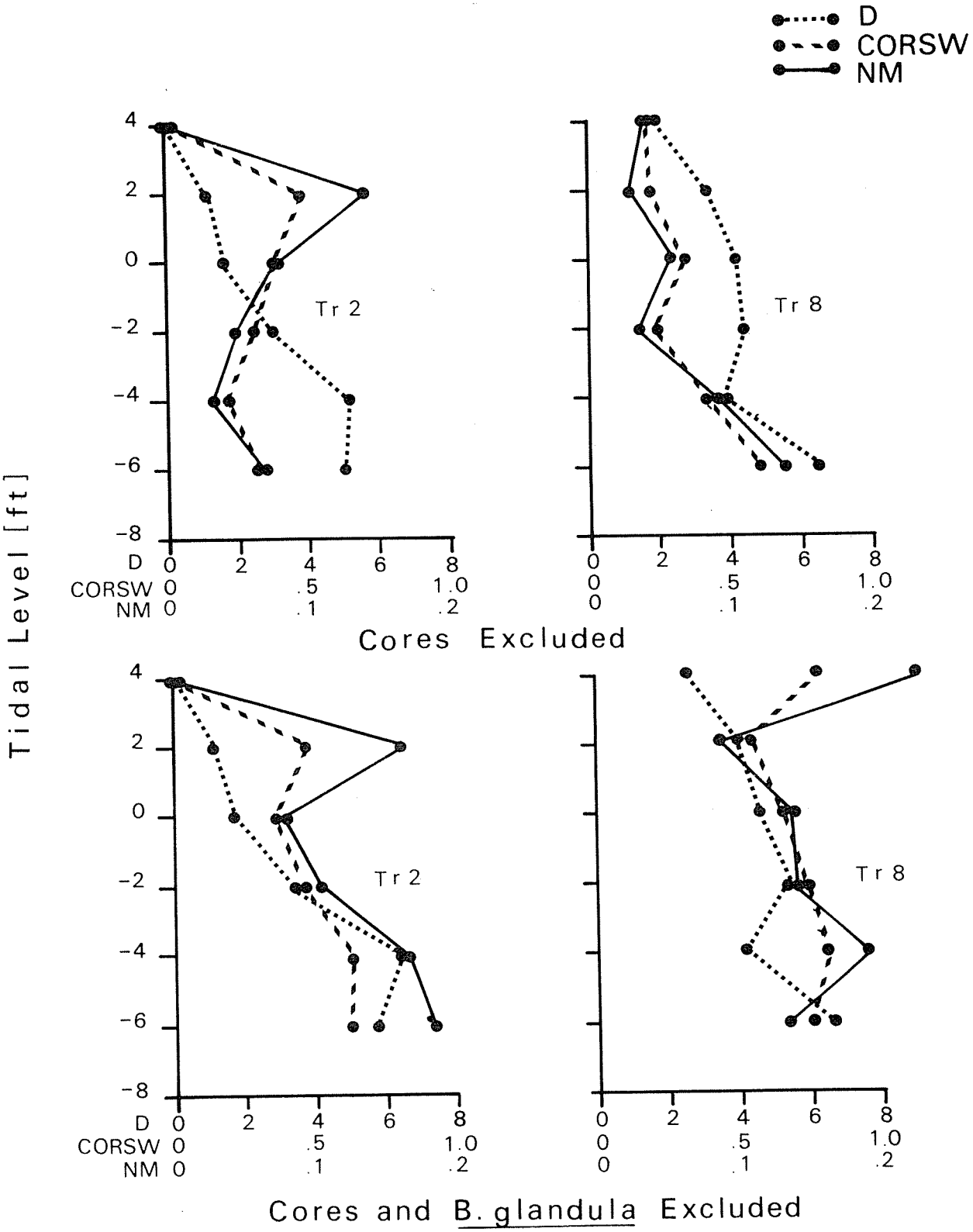


Fig. 7-7. Calculated diversity indices (D,CORSW,NM) on transects 2 and 8, demonstrating the effect of exclusion of *B. glandula* from the calculation. Nine samples (summer 1970 - summer 1971) progressively pooled.

cobble surface of the upper levels, there was a sharp reduction in the number of surface-dwelling animals and an increase in the number of species living within the substrate. Thus, the species richness was roughly the same as in the lower barnacle zone; but because no one species was as vastly abundant as *B. glandula* was at higher levels, the calculated diversities were much greater (Fig. 7-3). At the -8-ft level there was less wave action and more larger cobble permitting an increase in surface fauna over that of the -6-ft level. The few samples taken at -8 ft showed greatly increased species richness and diversity with the presence of many typically subtidal species. Most of the biomass present was composed of polychaetes, especially the tube builders (*Spionidae, Maldanidae, Terebellidae, Oweniidae*), bivalves, including *Macoma inquinata*, and the important sport clams *Protothaca staminea* and *Saxidomus giganteus*. Of these, only *Saxidomus* approached sufficient density to elicit any digging pressure and only in the vicinity of transect 4.

7.4.3.2 North side

Several major physical factors combined to give the beaches on the north side of the Island a vastly different aspect from those on the south side. The cliffs greatly restricted the physical extent of the upper zones, and in some areas (e.g., transect 8, -4 to -6 ft) the particle size of the substrate was considerably smaller than that of the cobble on the south side. The resulting instability prevented establishment of a "typical" well-developed community. The supralittoral fringe was present on the north side transects (6, 7, and 8) only on the rock cliffs and is thus considered in the discussion of the vertical transects.

Barnacles were present on large cobble and rocks as high as the +4-ft level, marking the top of the upper barnacle zone (Figs. 7-5 and 7-8). A few pockets of clean sand and gravel at that level had the same impoverished infauna characterizing this zone on the south side. The extent of the upper barnacle zone on the north side beaches was greatly limited by the cliffs and by the presence of significant infauna marking the start of the middle barnacle zone at the 0-ft level. *Fucus* was present erraticially on cobble as high as +4 ft and thus was not a reliable indicator of the middle barnacle zone. Distinction between the middle and lower barnacle zone was done as on the south side beaches on the basis of the character of the infaunal community.

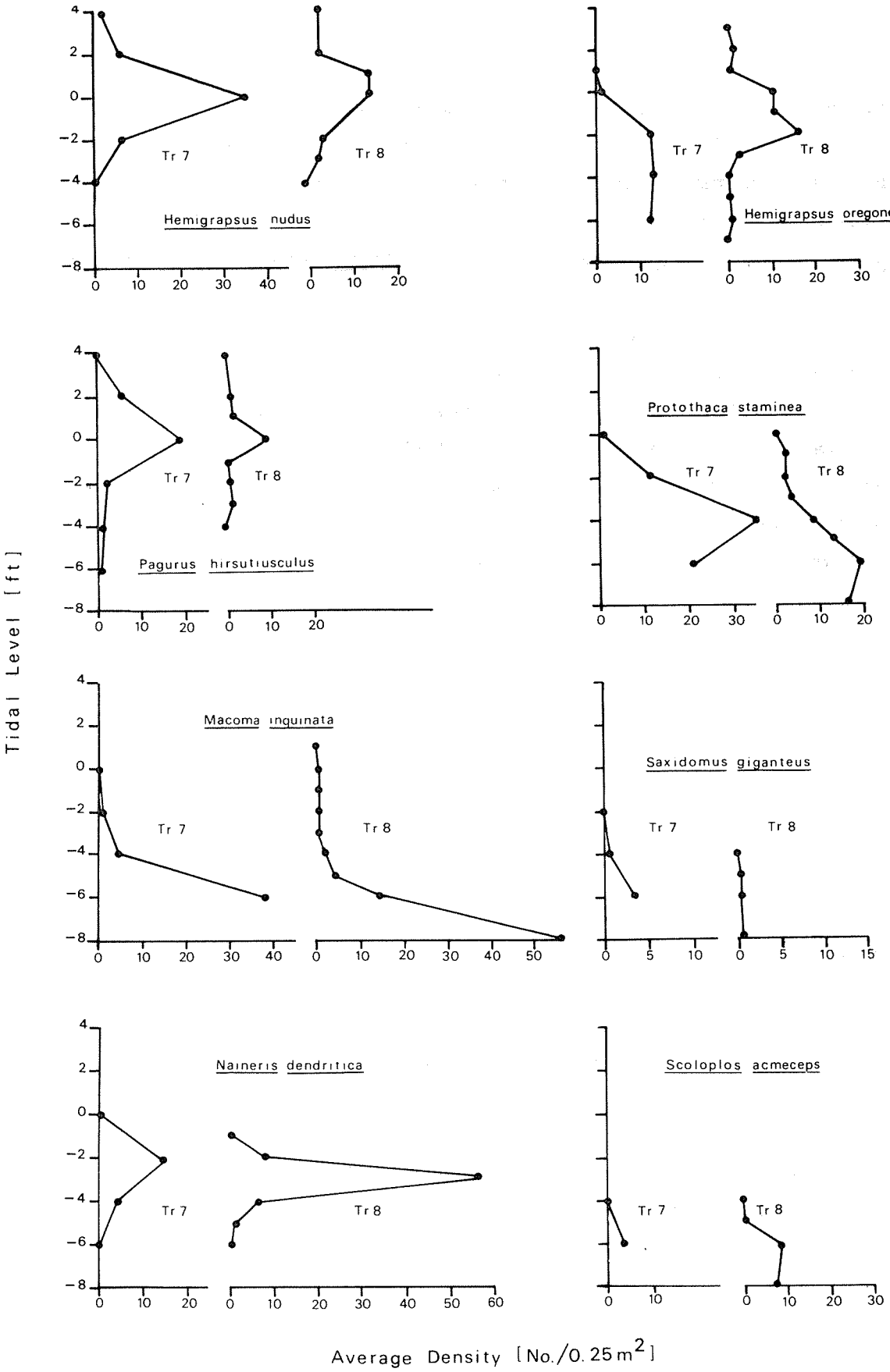


Fig. 7-8. Average density of selected invertebrate species from 2 years' sampling on 2 transects on the north side of Kiket Island. All figures based on 12 samples.

From mean sea level to above -2 ft, the infauna was composed predominantly of two species of larger polychaetes, *Lumbrineris zonata* and *Cirratulus spectabilis*, and lesser numbers of several species of polychaetes and bivalves that were abundant in lower zones (Fig. 7-8). The surface fauna of the middle barnacle zone was similar to that of the same zone on the south side although the infauna was considerably richer.

The samples taken from the -2-ft level to the -4-ft level contained sufficient parallels in numbers and types of organisms present to be considered as delineating the lower barnacle zone of the north side. Several species were abundant only at these two levels (*Naineris dendritica, Thelepus crispus, Golfingia pugettensis*). *L. zonata*, although a dominant species in the middle barnacle zone, reached its maximum densities here. The most important organism in this zone in terms of biomass and direct value to man was the steamer or native littleneck clam, *Protothaca staminea*. It reached its maximum density at the -4-ft level on transect 7.

The -5 ft level on transect 8 represented a transition from the lower barnacle zone to the *Zostera* zone of the north side and had an abundance of some organisms typical of either zone.

The *Zostera* zone reached its full development at -6 ft or below and was characterized by a sharp increase in species richness and diversity and the presence of many characteristically subtidal organisms (Fig. 7-3). Many species, particularly crustaceans and polychaetes, were unique to this zone on the north side. Of the polychaetes, *Notomastus tenuis* and the tube-building species present in this zone on the south side were most abundant. The edible clams *P. staminea* and *S. giganteus* were far more abundant than on the south side and accompanied by several less edible species (*Macoma, Tresus, Clinocardium*), comprised the bulk of the biomass of this zone. The brittle starfish *Diamphiodia occidentalis* was present locally in such concentrations that their arm tips were nearly in contact with those of adjacent individuals.

7.4.3.3 Transect 1

The sampling of only five levels on the sandy beach of transect 1 was insufficient to clearly establish boundaries of zonation in the subsurface fauna. The moderating influence of the percolation of run-off water through

and over the broadly sloping sand would be expected to produce a gradual transition from one community to the next.

An upper zone comparable to the supralittoral fringe on the cobble beaches, was discernible extending from the high-tide line through the +3-ft level and populated by scattered aggregations of the beach hopper *Orchestia traskiana*, an unidentified oligochaete, and a few *Macoma inconspicua*.

At the +1-ft level there were large numbers of *M. inconspicua* and the burrowing ghost shrimp *Callianassa californiensis*, although neither was as abundant as at lower levels. Several sand-dwelling polychaetes were present, most of which were also more abundant at lower levels. One species, *Euzonus williamsi*, was present in 6 of 12 samples at +1 ft, yet was found nowhere else on the Island. This level was called the "upper *Macoma-Callianassa* zone" and was found to differ from the "lower *Macoma-Callianassa* zone" in having fewer species present and very few of the bivalve *Cryptomya californica*, which was abundant in the burrows of *Callianassa* at lower levels. Other than these changes and an increased polychaete fauna, the lower *Macoma-Callianassa* zone was rather uniform from the -1 ft through the -3 ft level.

The upper edge of the *Zostera* zone was encountered at -5 ft. Although this zone was continuous along the south side of the Island, it consisted of uniform fine mud with no cobble in the cove of transect 1, as opposed to along the rest of the Island where some cobble was present. Species composition was therefore considerably different and the densities of *Saxidomus* and *Protothaca* were lower than along the rest of the south beaches. Most of the species found in the lower *Macoma-Callianassa* zone were also at this level and several reached their highest densities here, including *M. inconspicua* and the sandworm *Nephtys caeca*.

7.4.4 Zonation on the Vertical Transects

The presence of a distinct zonation pattern on the cliffs making up the majority of the upper and middle intertidal on the north side of Kiket Island was more plainly visible than on the cobble beaches of the south side. The basic patterns described for the epifauna on the south side beaches were also present on the cliffs and generally included the same types of organisms, if not the same species. The tidal levels at which each zone occurred were 1.5 to 4 ft

higher on the north-facing cliffs than on the south-facing cobble. The same zones on the limited rock areas of the south side were 1-2 ft lower than on the north cliffs. Levels given below varied plus or minus 0.5 ft depending on shading from, or exposure to, the late afternoon sun.

The supralittoral fringe on the vertical belt transects of the north side of Flagstaff Point (Fig. 7-1) extended from the high-water line to +4.5 ft level. This uppermost region was again characterized by the virtual absence of attached fauna with the exception of a few scattered *B. glandula* in some very protected crevices. Other organisms present were *Littorina scutulata*, the semiterrestrial isopod *Ligia pallasii* and the black lichen *Verrucaria*. The low and reltively even numbers of each of these species resulted in very high diversities (Fig. 7-9); thus, these do not represent the true impoverished nature of this fauna.

The upper barnacle zone showed as a narrow white band between the black of the supralittoral fringe at about +4.5 ft and the dark *Fucus* of the middle barnacle zone at +3.5 ft. Animals characteristic of this zone were *Acmaea digitalis, Ligia pallasii, Littorina scutulata,* and *L. sitkana*, in addition to the barnacles, *B. glandula* and *C. dalli* (Figs. 7-10 and 7-11). Because of the great abundance of *B. glandula*, the calculated diversities dropped sharply; but the increased species richness (D) reflected the increased complexity of this zone over that of the supralittoral fringe (Fig. 7-9).

Below the 3.5-ft level there was an increase in diversity (SW) associated with the presence of substantial *Fucus* cover. The dominant animal species remained the same as in the upper barnacle zone, but five other species reached their maximum densities here (*M. edulis, Emplectonema gracile, Syllis adamantea, Thais lima,* and *Acmaea paradigitalis*).

Although not readily obvious in a cursory view of the cliffs, perhaps the most striking faunal break observed occurred at +2 ft with the transition from the middle to the lower barnacle zone. A few species, notably *B. glandula, B. cariosus, E. gracile,* and *H. nudus*, were found in profusion both above and below this level. However, of the 27 species (with more than one individual) present at either the +3 or +1-ft levels, 11 reached either their highest or lowest range at the +2-ft level. The large degree of overlap of species ranges at this level is evident as a peak in the plots of total number

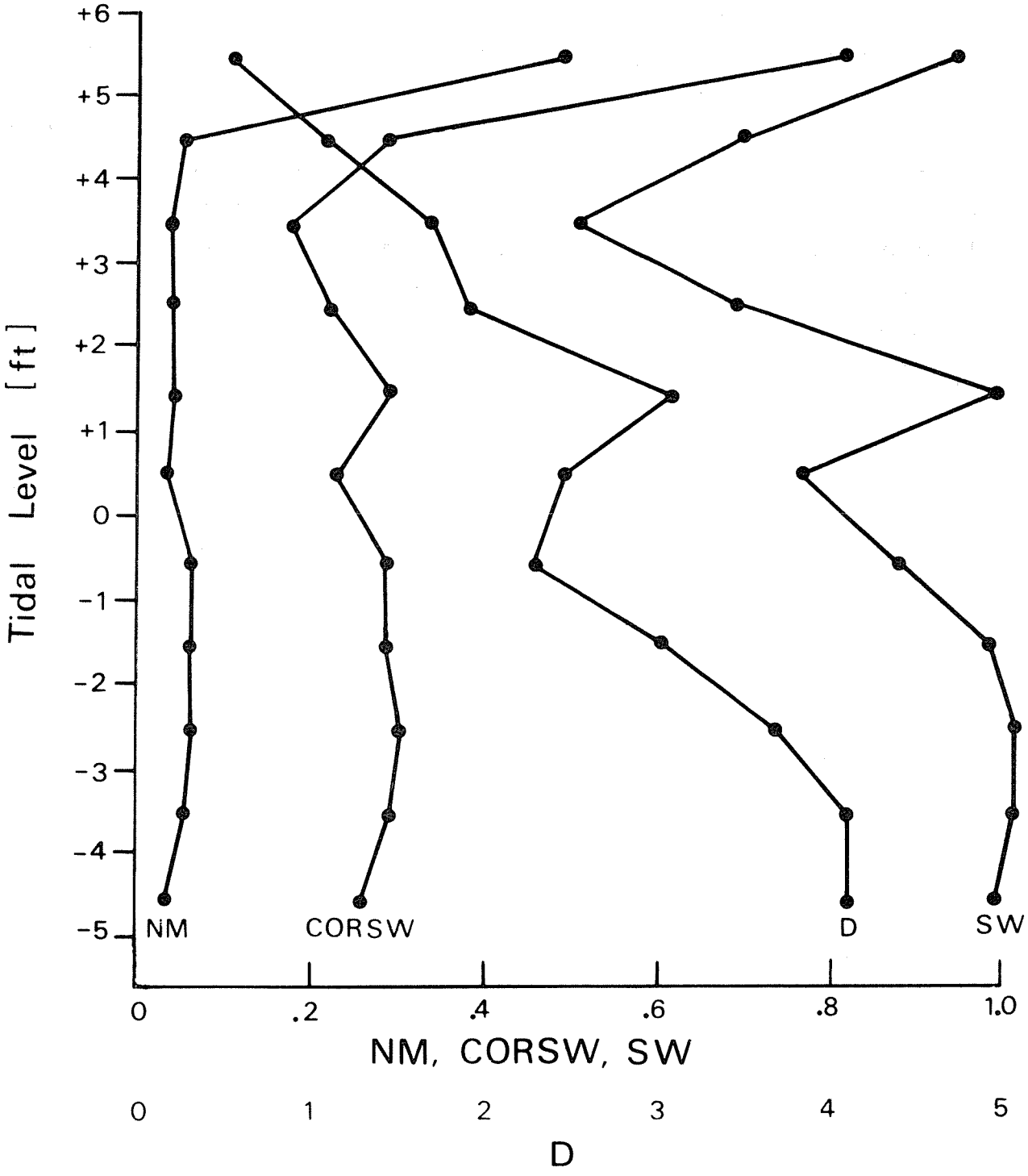


Fig. 7-9. Calculated diversity indices (D, NM, CORSW, SW) on the vertical transects. Eight samples, at each level, progressively pooled.

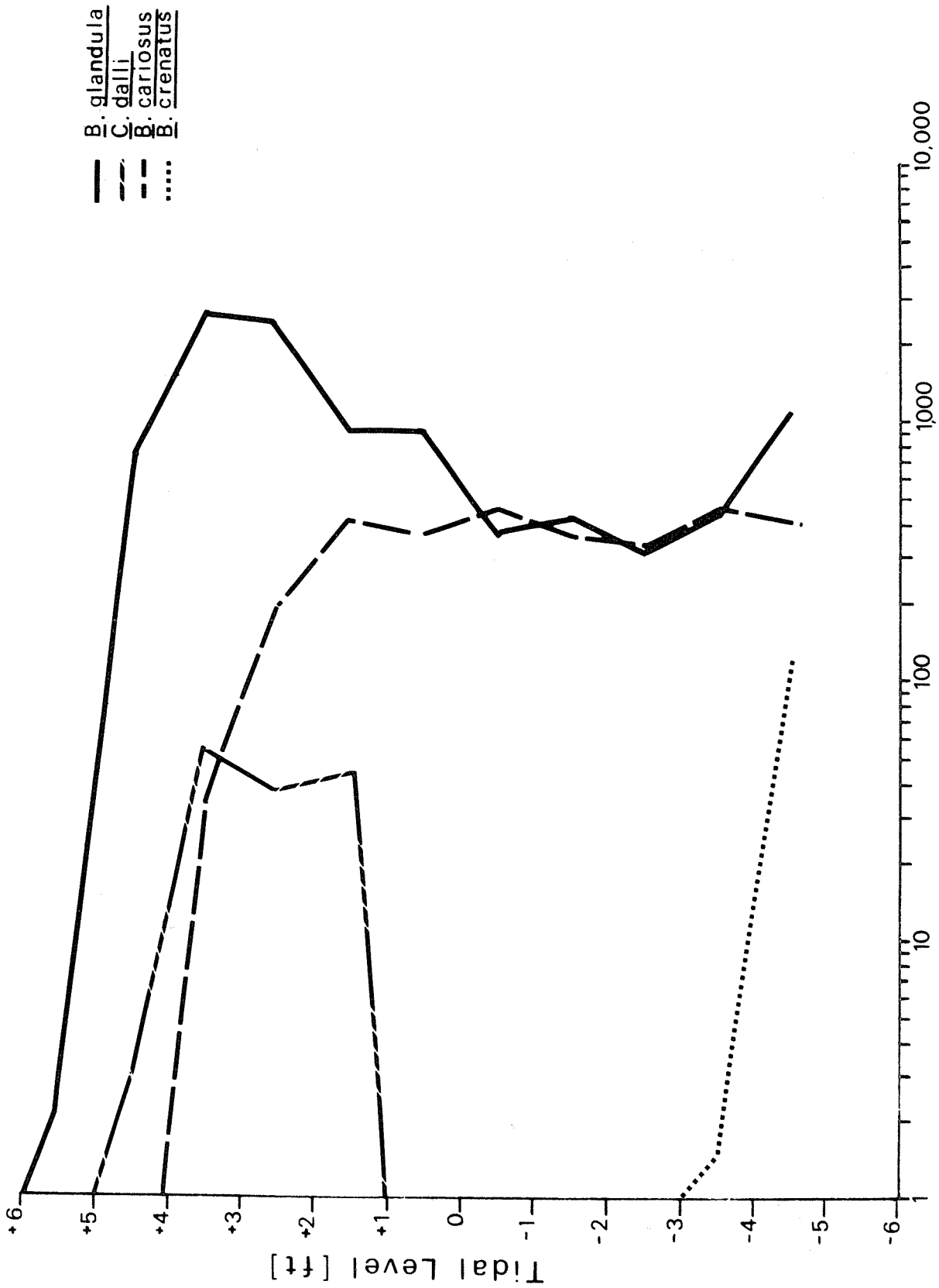


Fig. 7-10. Average density of four barnacle species on the vertical transects, based on eight 0.1 m^2 samples at each level.

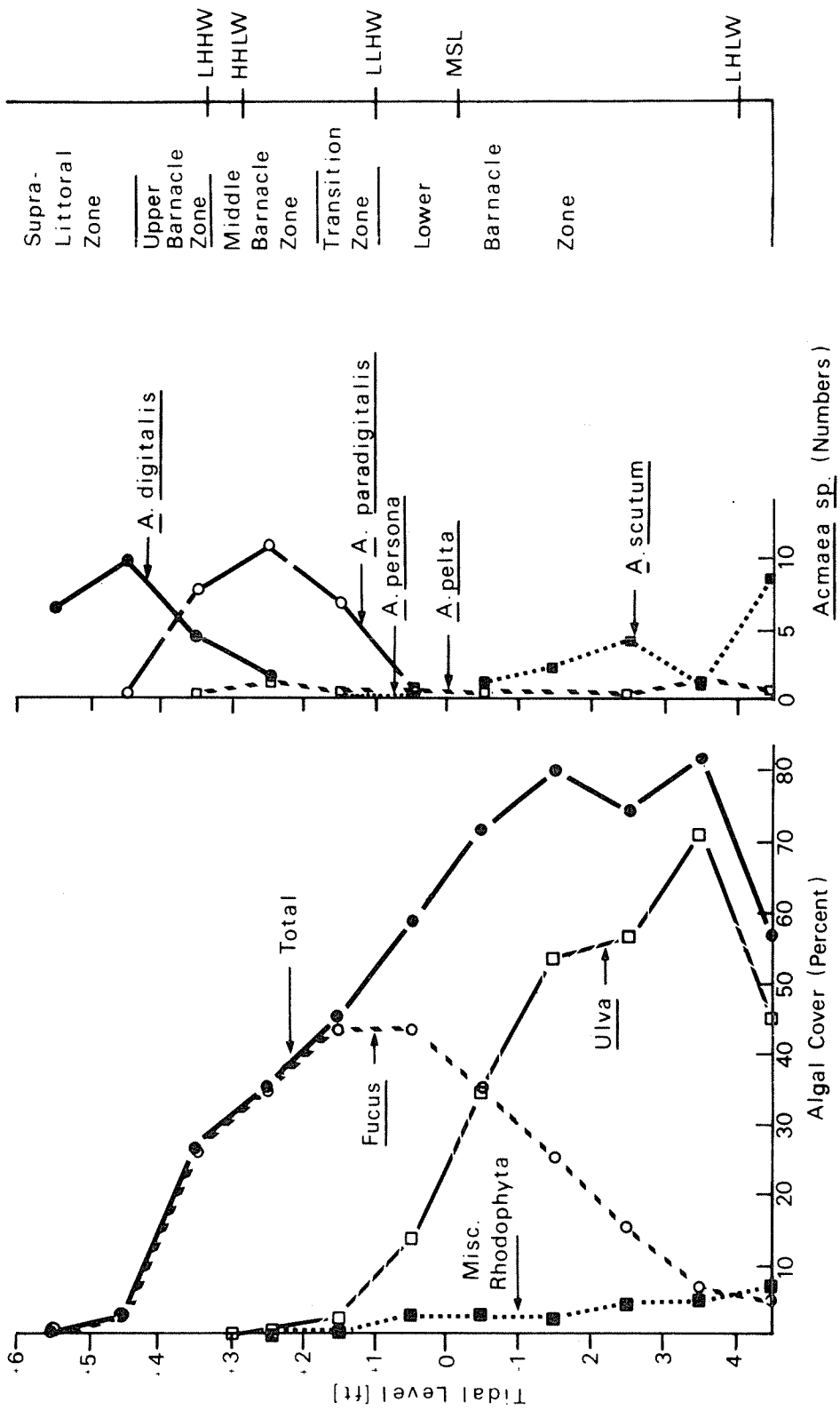


Fig. 7-11. Vertical distribution of algae coverage and 5 species of limpets on the cliff transects, based on 8 samples at each level.

of species, numbers of species with upper or lower limits, and diversity (SW, CORSW, D) versus tidal level (Figs. 7-9 and 7-12).

At +2 ft *B. cariosus* took over dominance in terms of occupation of primary space from *B. glandula*, although the latter species remained abundant at lower levels. In addition to the barnacles, species typical of the lower barnacle zone were the herbivores, *Katherina tunicata, Oncidiella borealis, Ampithoe simulans,* and *Idothea wosnesenskii*, the scavengers *H. nudus* and *Pagurus hirsutiusculus*, and the predaceous starfish *Leptasterias* sp. Percentage cover of algae was high, as reflected by the large number of herbivores, and species included several of the Rhodophyta in addition to *Fucus* and *Ulva*. From about mean sea level *Ulva* exceeded *Fucus* in percentage of cover and gradually increased at lower levels as *Fucus* declined.

At +1 ft species diversity dropped sharply from the peak at the +2 ft transition, then increased to the -1 ft, and varied but slightly below. The species composition of the lower barnacle zone community remained rather constant from its upper limit to the -1-ft level, then gradually increased in species richness with decreasing tide level. At -3 and -4 ft some species typical of the *Laminaria* zone were encountered, (*Balanus crenatus, Thais lamellosa, Metridium* and sabellid worms), but the termination of the cliff at about the -5-ft level precluded full realization of this zone. Where the *Laminaria* zone did occur at Kiket Island it was marked by larger numbers of anemones, sabellid and serpulid worms and a sharp decrease in the density of adult barnacles, the result of predation by *Pisaster ochraceus*, and *T. lamellosa*. A substantial increase in variety of algae also was evident, including *Laminaria, Alaria, Costaria, Iridaea, Ptilota* and a profusion of other Rhodophyta.

In general there was good agreement between the results of sampling in the summers of 1970 and 1971, although three of the major faunal components differed significantly between the two years, as shown by t-tests. *Balanus glandula* was significantly more dense in the middle and upper barnacle zones (+5 to +3 ft) in 1970. In the lower barnacle zone (0 to -2 ft) abundance was significantly greater in 1971. The average density of *P. hirsutiusculus* at each level of its range (+2 to -4 ft) proved significantly greater in 1970. Percentage of cover of *Ulva* at the 0 to -3-ft tidal levels was significantly greater in 1971.

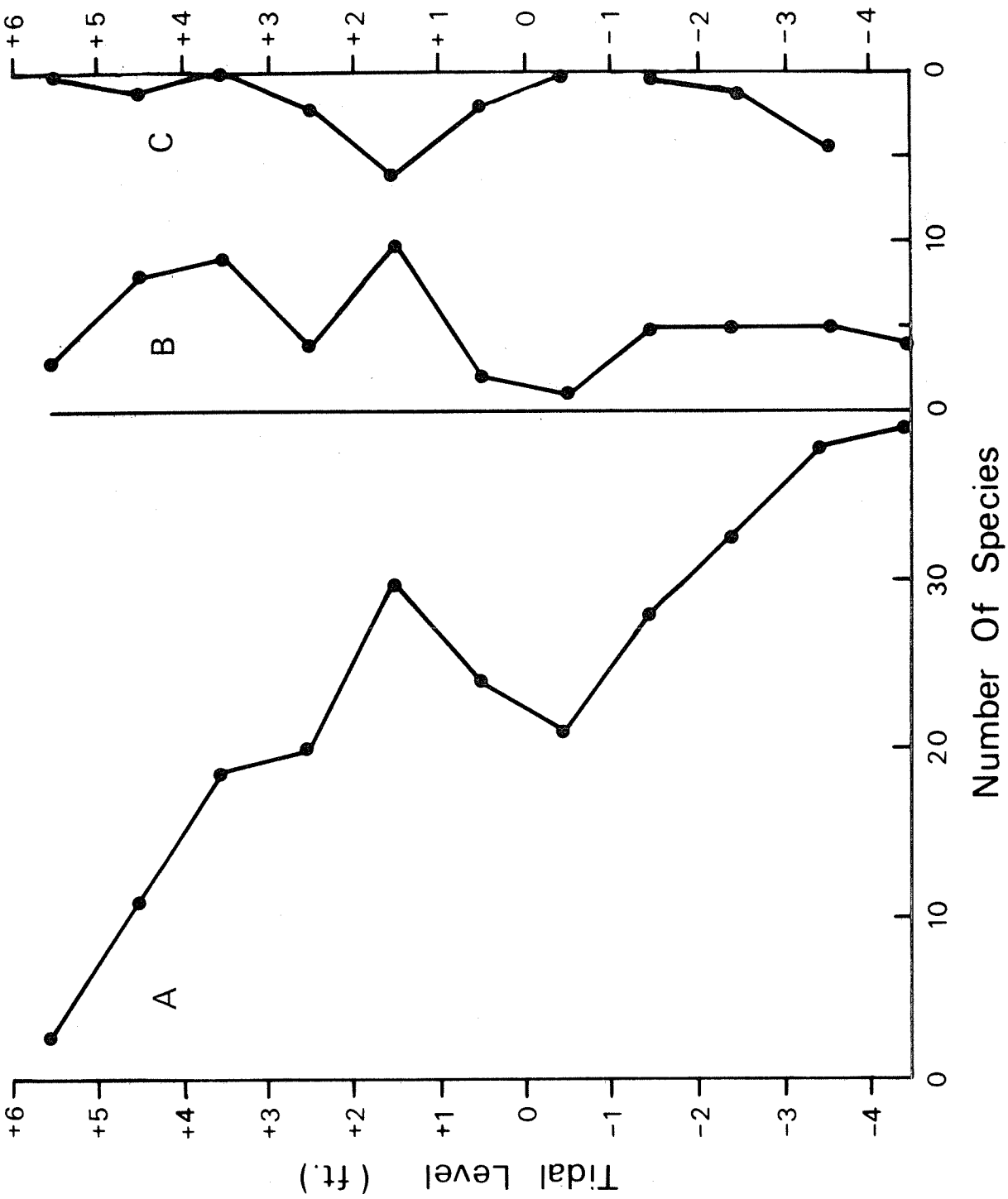


Fig. 7-12. Number of species of invertebrates on the vertical transects.
A. Total from 8 samples in 2 summers.
B. Number of species with upper limit of range at given level.
C. Number of species with lower limit of range at given level.

Apart from these three species the distributions and tidal height of peak abundance of all common organisms were similar in the two summers of sampling. The graphs of the several indices of diversity for the two summers are also in close agreement except at the +5-ft level, where the preponderance of *B. glandula* in 1970 noticeably depressed the values of NM, SW, and CORSW (Fig. 7-9).

Vertical ranges of the 50 most abundant animals on the vertical transects are summarized in Table 7-2.

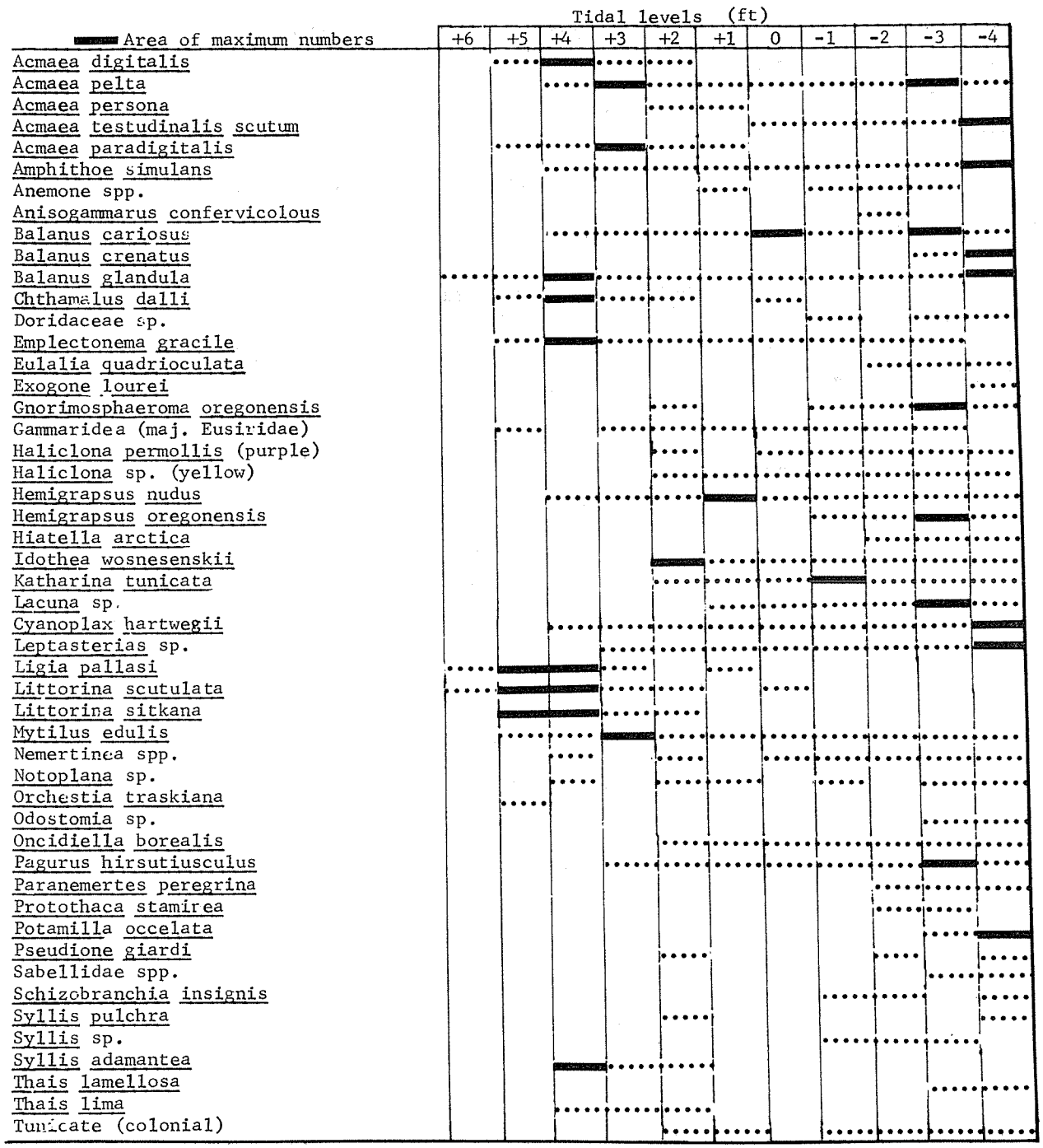
7.4.5 Seasonality in Algal Cover

Seasonality was evident in the percentage of cover by all algal species, although it was much less pronounced at upper than at lower tidal levels (Figs. 7-13 through 7-18). At higher tidal levels (above MSL) there were no foliacious algae on any of the sand, gravel, or smaller cobble on the south side of the Island. On the larger boulders and on rock outcroppings, the dominant species was the perennial brown rock kelp (*Fucus distichus*), although the average percentage of cover at upper levels on the south side was less than on the north because of the lack of large areas of this preferred substrate (Fig. 7-13). On the rocky bench at transect 5 (not included in the averages shown) *Fucus* was extensive from +2 ft to -2 ft, with coverage between 25 and 100 per cent during most of the year.

The higher algal coverage at upper levels on the north side transects reflects the rocky nature of the substrate and the protection against desiccation afforded by the northern exposure. *Fucus* and other species (*Gigartina, Iridaea*) were relatively abundant up to +4 ft on the northern cliffs, whereas they were virtually absent above +3 ft on similar rocks with southern exposure.

At any given location there was a tendency for a major reduction in coverage of *F. distichus* every other winter following release of gametes because of its biennial reproductive cycle (Powell, 1957). A partial resurgence in the coverage would begin the next spring and continue through the winter and the second summer. Because these cycles were not in synchrony at all locations about the Island, the maximum variation in the cover of *Fucus* at any level was from 17 per cent (March) to 37 per cent (June) at +2 ft when averages are considered over six transects and two plus years. As

Table 7-2. Presence of 50 most abundant invertebrates on the vertical transects. Solid bar indicates level(s) of maximum density



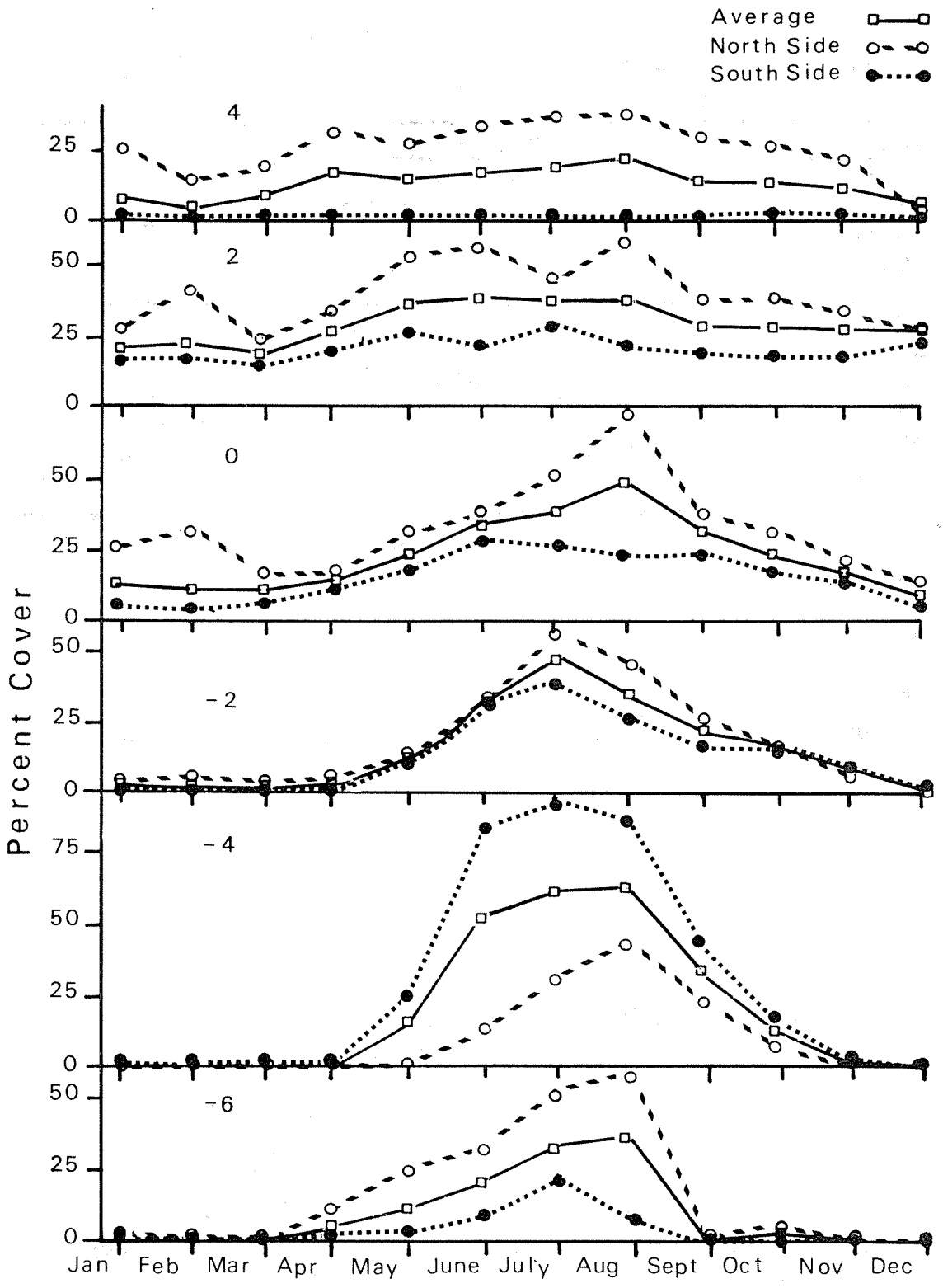


Fig. 7-13. Annual variation in total percentage cover of all algae species at 6 tidal levels on 6 transects (3 north side, 3 south side). Averaged over period April 1970 to July 1972.

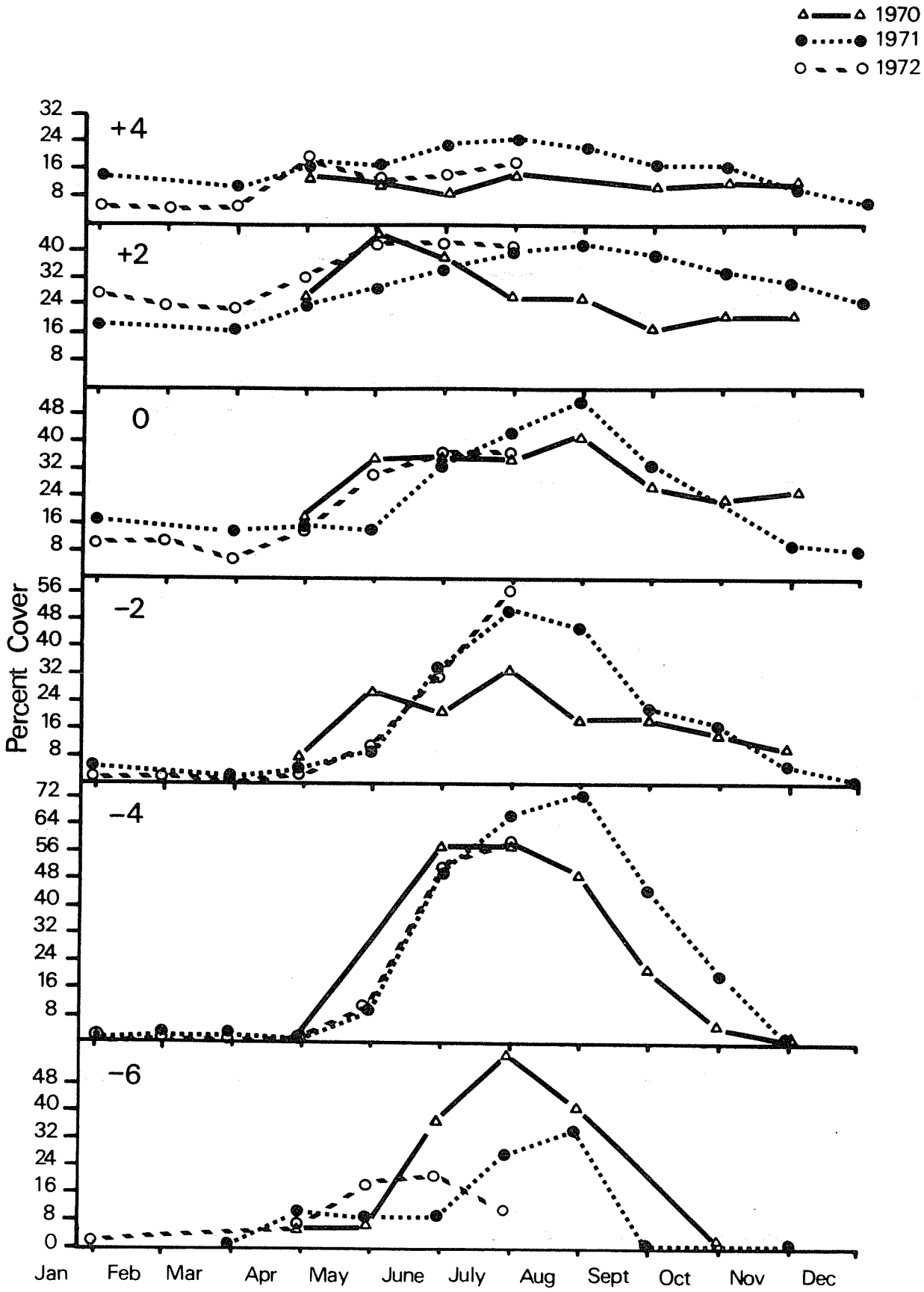


Fig. 7-14. Annual variation in total percentage cover of all algae species at 6 tidal levels for period April 1970 to July 1972. Averaged over 6 transects.

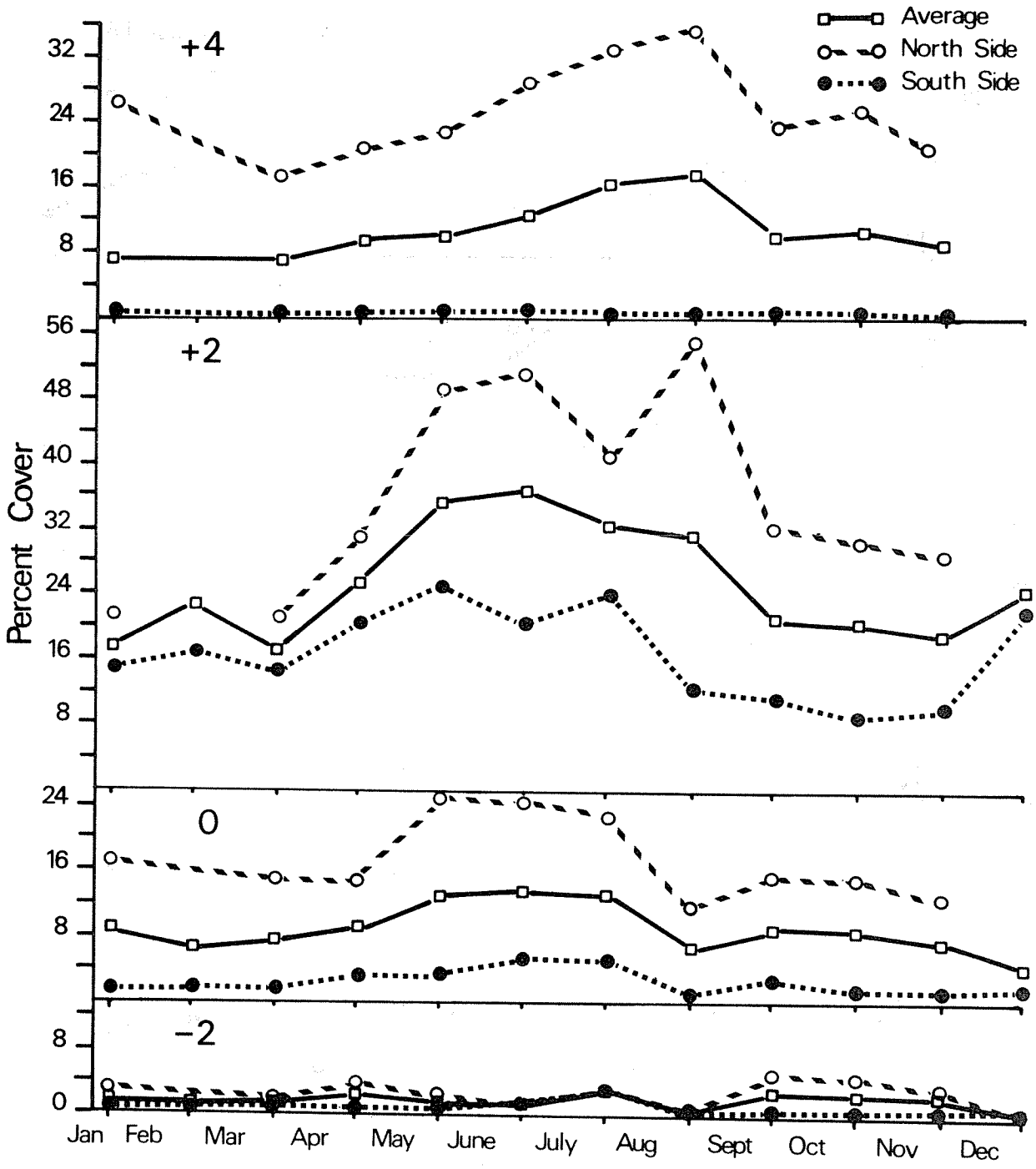


Fig. 7-15. Annual variation in percentage cover of *Fucus distichus* at 6 tidal levels on 6 transects (3 north side, 3 south side). Averaged over period April 1970 to July 1972.

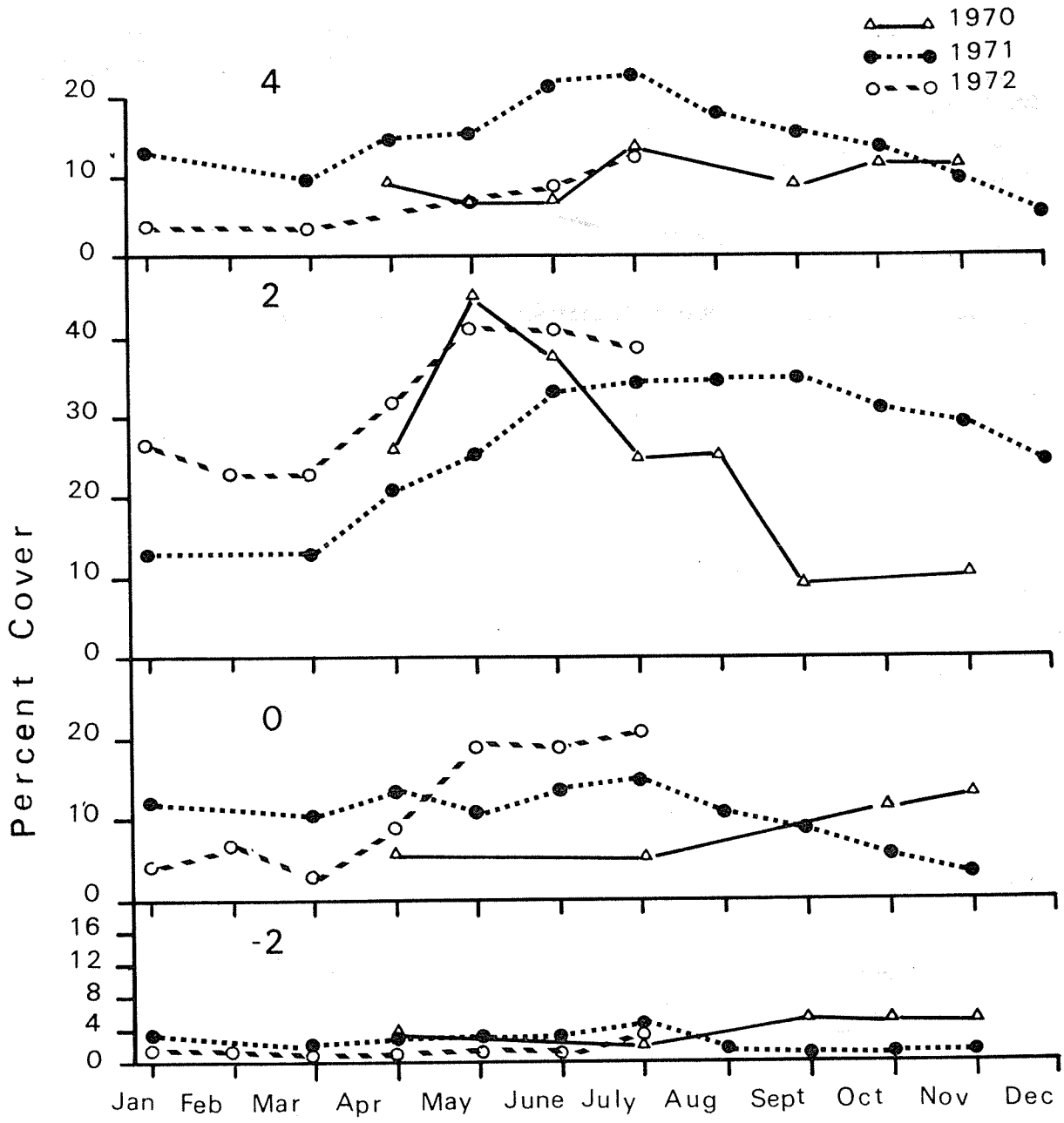


Fig. 7-16. Annual variation in percentage cover of *Fucus distichus* at 6 tidal levels for period April 1970 to July 1972. Averaged over 6 transects.

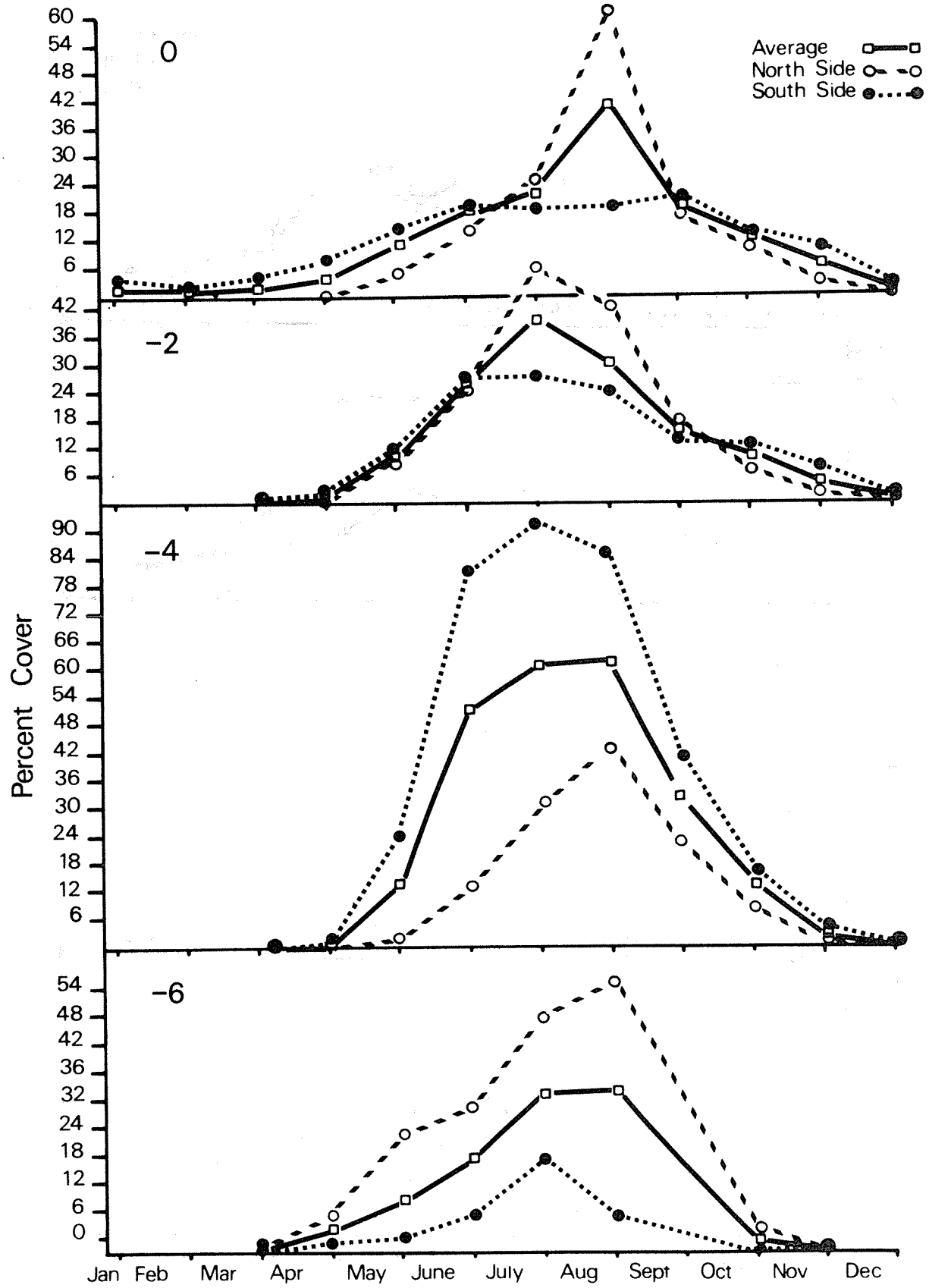


Fig. 7-17. Annual variation in percentage cover of *Ulva lactuca* at 6 tidal levels on 6 transects (3 north side, 3 south side). Averaged over period April 1970 to July 1972.

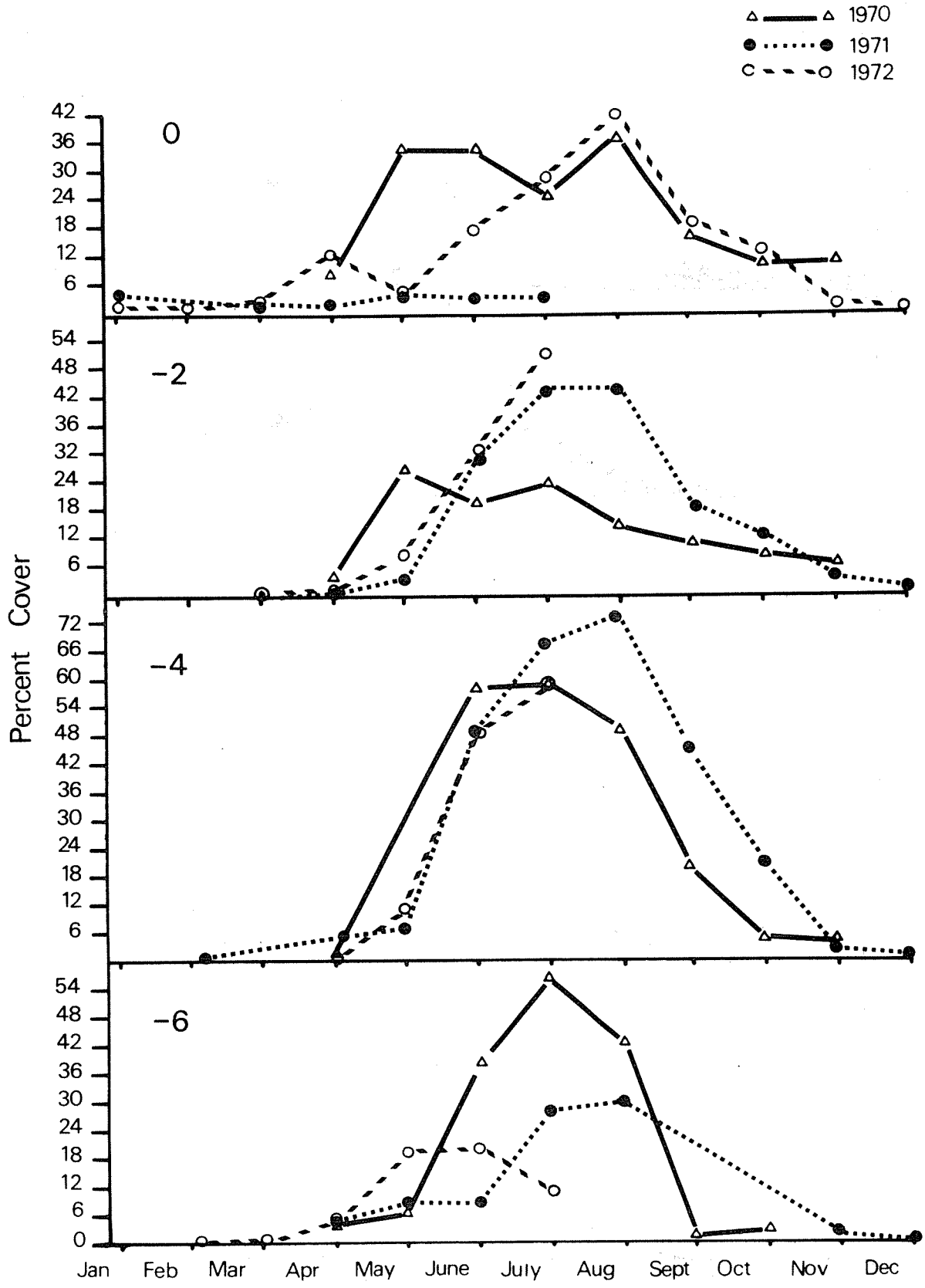


Fig. 7-18. Annual variation in percentage cover of *Ulva lactuca* at 6 tidal levels for period April 1970 to July 1972. Averaged over 6 transects.

smaller subsets of data are inspected (individual years, Fig. 7-16; separate sides of the Island Fig. 7-15), greater annual variations become apparent, since extremes of from 100 per cent to less than 10 per cent were recorded in the course of the study on one plot.

Despite these local fluctuations, the percentage of cover of algae on the *Fucus*-dominated rocky areas varied less, seasonally than on the lower beaches (Fig. 7-13). Below mean sea level, the cobble and sand substrate (again with the exception of transect 5) prevented the establishment of abundant perennial algae. In these areas the opportunistic "pioneer species" *Ulva lactuca* achieved complete dominance among the algae during the summer months (Figs. 7-17 and 7-18). Responding rapidly to increased insolation in April and May, this annual extended its coverage from near 0 per cent to virtually 100 per cent cover along a broad band of beach and in many areas was continuous subtidally. At -2 and 0 ft the peak in the curve of *Ulva* coverage is much sharper and higher on the shaded north side of the Island than on the exposed south side. Here the curve is flattened from June through August (Fig. 7-17) probably because of inhibition of growth by excessive light and/or desiccation. At -4-ft, *Ulva* did much better on the south side possibly because of near optimal conditions of illumination and immersion time. Densities were less at -6 ft on the south side because of the instability of the sandy region at the upper edge of the *Zostera* zone.

7.4.6 Distribution, Age, Growth, and Production of *Protothaca staminea*

7.4.6.1 Distribution

Among pelecypods important to local recreational diggers, the native littleneck clam, *Protothaca staminea*, was by far the most abundant and widely distributed at Kiket Island. Analysis of variance showed significantly higher densities (at the .90 level) on the north side transects (Figs. 7-4 and 7-8). Densities were greatest in the -4 to -6-ft tidal range with occasional concentrations as high as -2 ft and as low as -8 ft. The preferred substrate was silty mixed gravel, coarse sand, and shell, frequently with considerable cobble present. At higher tidal levels, greater numbers were found where there was rock bench underlying the gravel substrate, apparently because of the increased water retention (e.g., transect 5 and 6 at -2 to +1 ft). The

maximum density at any location was at -4 ft on transect 7 (33.6 ± 5.8 per 0.25 m^2), and the peak number in any sample was 60 at that level. A total of 1921 individuals was taken in beach sampling, and the average estimated density for any 0.25-m^2 area below mean sea level was 6.1 clams.

7.4.6.2 Age Determination

The results of tagging and monthly sampling proved conclusively the validity of the method of age determination, which formed the basis of the study of the age and growth of *Protothaca staminea*. The method makes the assumption that at least some of the concentric rings laid down in the external sculpture of the shell are the result of annual winter growth checks and that these may be reliably distinguished from the majority of rings or checks caused by other phenomena. To prove this for the population at Kiket Island we considered it necessary and sufficient to establish the following: (a) that the amount of growth since the last "annulus" increased in a regular manner during the growing season and that this growth increment approached the measured annual increment attributed to each age class for clams taken at the same tidal level on a nearby beach transect; (b) that no new rings were laid down during the growing season that were as prominent as the "annuli;" and (c) that the checks resulting from even such severe disturbance as digging and tagging by filing of the shell would produce in most instances checks less severe than, and distinguishable from, those of the wintertime reduction in growth.

A composite plot of the linear regression lines of the new season's growth (ΔL) on the age of each clam for each month from May through October is shown in Fig. 7-19. Although the decrease in ΔL with increasing age is more nearly logarithmic than linear, the raw data show clearly the regular pattern of increasing ΔL for each month through the end of September. Unfortunately, this series of samples was not begun until the end of May 1972. Growth prior to that time was estimated based on observations that *P. staminea*, especially the younger individuals, taken in the beach transect sampling had significant new growth by the end of March and some detectable growth as early as February.

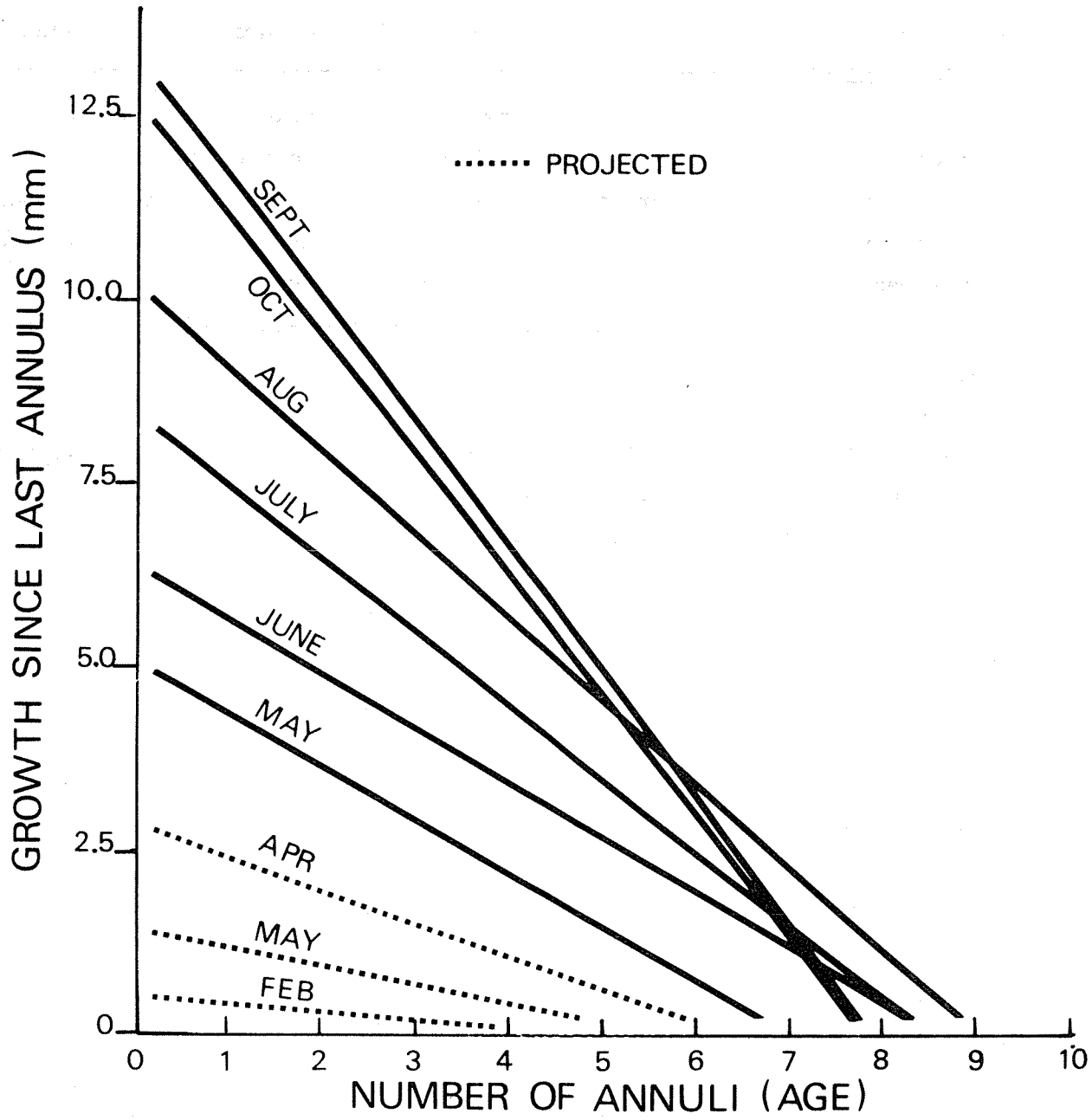


Fig. 7-19. Month-by-month plots of new growth (Δ L) for *P. staminea* of various ages. May through October based on monthly samples (minimum n = 34). February through April projected on the basis of observations from beach transect sampling.

The month-by-month increase in the mean of the new growth for two year classes and the final ΔL achieved during the season for clams 2-5 years old are shown in Fig. 7-20. The pattern of increase in growth as measured for the other year classes was less regular than the two shown because of the small sample sizes but the trend was similar. The comparable ΔL for each year class calculated from measurements of annular rings of clams taken at -4 ft on transect 6 are also shown. Transect 6 was selected as the transect most closely approaching conditions in the cove in front of the laboratory where the monthly samples were taken. The hypothesis that the final season's growth measured from the monthly samples (taken on November 4) was equal to the difference between the measured annuli for the same age classes on transect 6 at -4 ft was tested with a t-test and was accepted at all levels of significance (maximum t was 1.01).

In all of the monthly samples taken no abnormally small values of ΔL, that would indicate a check had been formed during the growing season, were measured for younger age classes. Moreover, none of the clams marked and replanted at the end of May, June, and August produced any prominent checks between the time of marking and the time of recovery in early November. Checks from the disturbance of digging, handling, and replanting were in all cases detectable, although for some clams it was first necessary to reference the exact length measured at the time of first digging before this check could be found. The checks from this handling were subjectively judged as to severity on a scale of from 1 to 3, with those designated as "3" approaching the level where they might be confused with annuli. In clams dug and replanted in May the average severity of this disturbance check on unmarked clams was virtually identical to that on clams marked by filing a series of /'s or X's on either side of the shell (n = 15 and 17, $\bar{x}$ = 1.60 and 1.59). Some clams from the June and August samples were marked by filing a "V", 1-2 mm deep in the ventral margin before replanting. This type of mark caused generally more distinct disturbance checks than merely filing on the outside of the shell because of damage to the mantle and the need to fill the irregularity in the shell (n = 35, $\bar{x}$ = 2.06). It was estimated that 10 to 15 per cent of those clams dug and replanted, both with and without marking, had disturbance checks of such severity as to be confused with annuli.

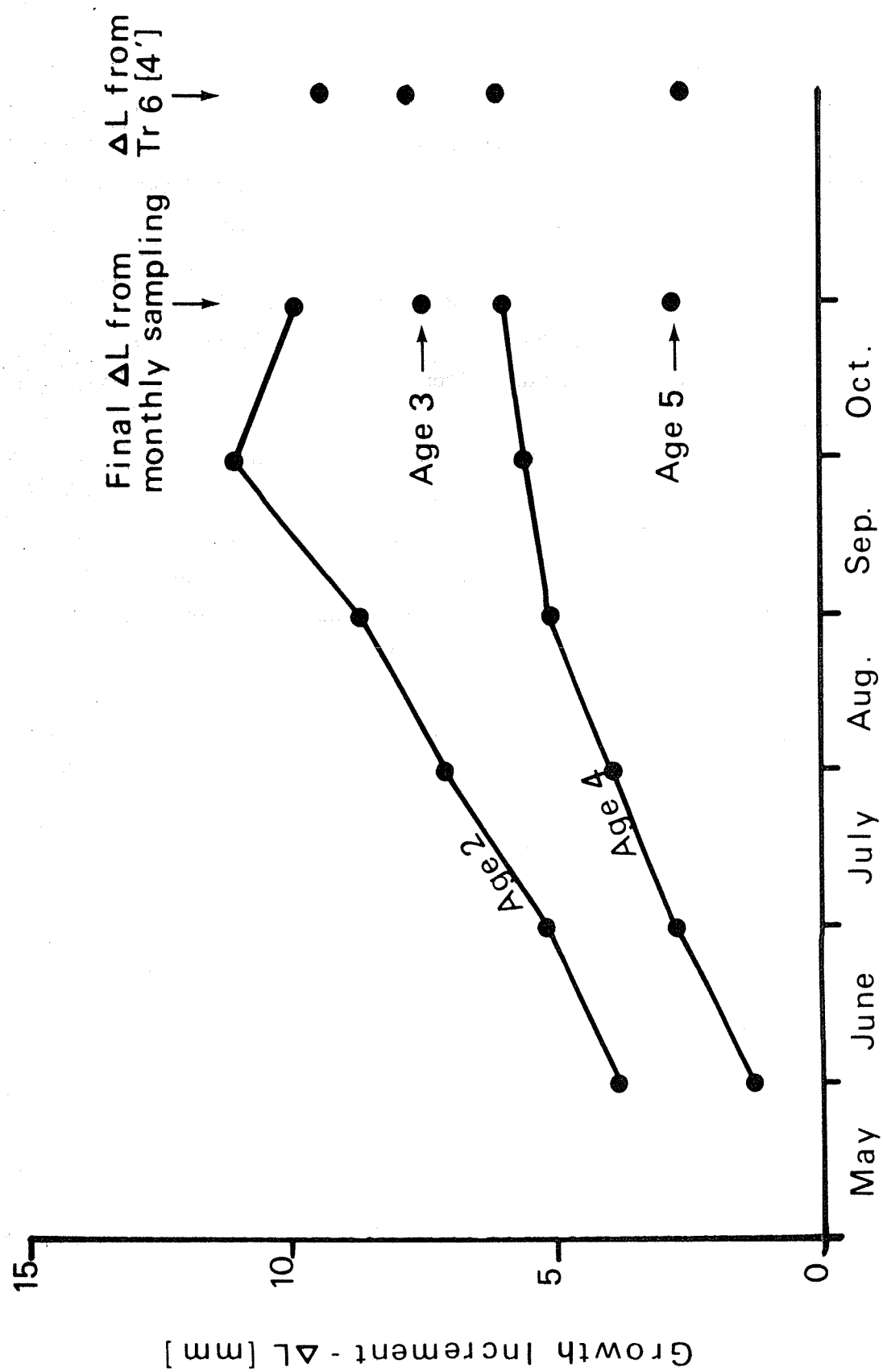


Fig. 7-20. Month-by-month increment of new growth (ΔL) for two age classes of *P. staminea*. Also shown are the final ΔL from the monthly sample at the end of October 1972, for ages 2-5 and the comparable ΔL calculated from measurement of annuli on all clams taken at -4 ft on transect 6.

7.4.6.3 Growth

Measurements of shell dimensions, weight, age, and length of each annulus were made where possible on 1921 *Protothaca* taken in the beach sampling. The mean length for each annulus of *P. staminea* has been plotted against age to demonstrate graphically the variation in growth rates between transects over all levels (Fig. 7-21), between transects at a single level (Fig. 7-22), between levels over all transects (Fig. 7-23), and between the various levels on single transects (Figs. 7-24 and 7-25). In all cases the mean lengths of each annulus for each location were taken from all clams collected in the 2 years of sampling. Averaging over at least two year classes for each value (more than two for most) helped to smooth the effects of particularly good or bad growing seasons. Because of the diminishing numbers in each successive age class, the data points for older ages were based on progressively fewer observations and tended to behave erratically in some cases because of statistical fluctuations and possibly because of size selective mortality. When the number of observations of a given annulus was less than 10 the curve was terminated if the mean length for that annulus deviated greatly from the smoothed curve established from the earlier annuli.

Certain general trends are obvious from inspection of these figures, but statistically significant differences in growth rate were determined by a fit of the von Bertalanffy growth equation to data from the various locations. The parameters L_∞ and K in the equation

$$L_t = L_\infty (1-e^{-K(t-t_o)}) \qquad (1)$$

where L_t = average length at time t,

L_∞ = theoretical maximum length for which growth rate is zero,

K = a measure of the rate at which length approaches L_∞, and

t_o = theoretical age at which length = 0

were obtained by use of the methods described by Gulland (1969): The slope of the regression line of change in length during the year ($\Delta L = L_{t+1} - L_t$)

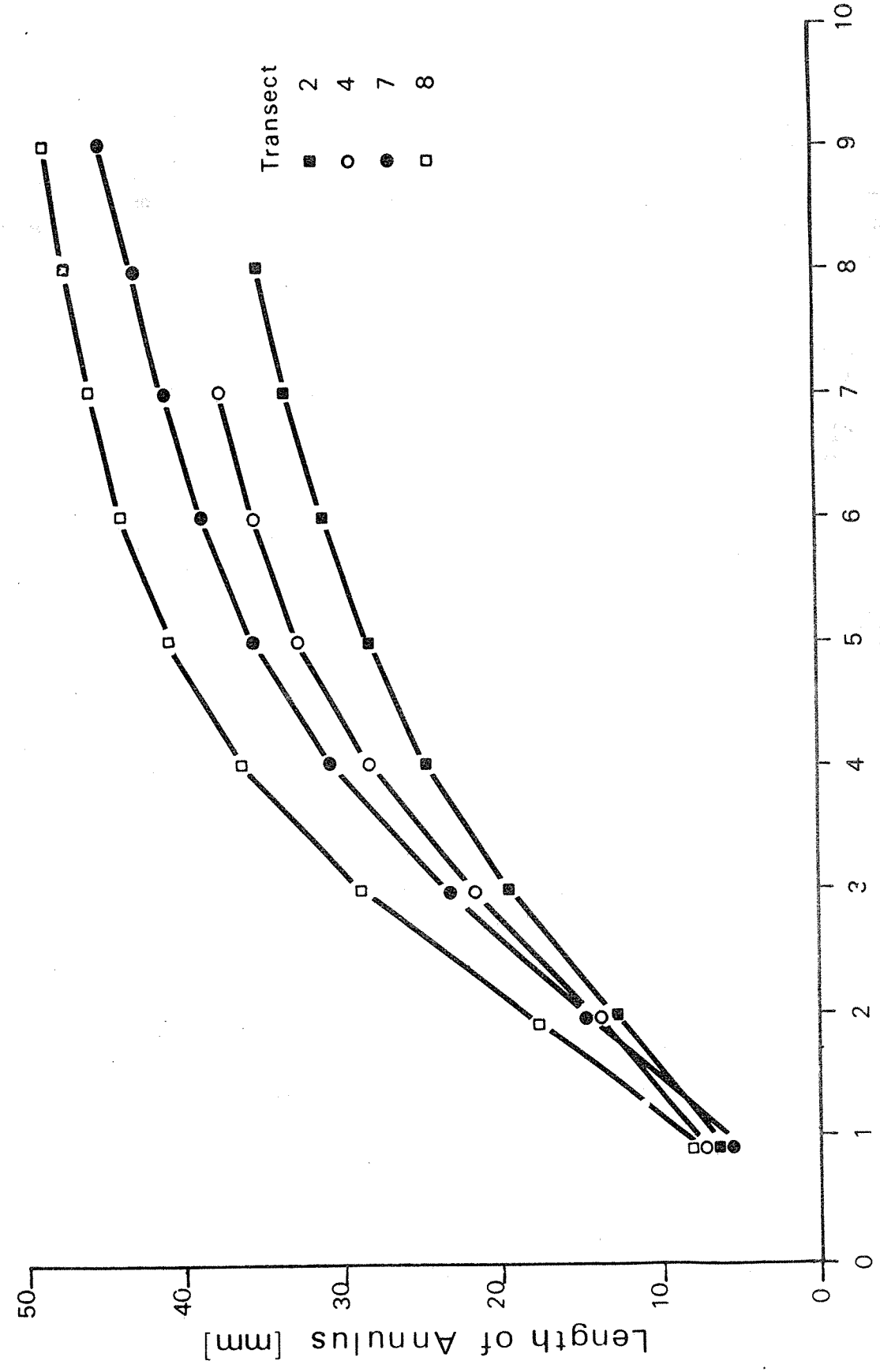


Fig. 7-21. Growth of *P. stamínea* on four transects from measurements of annular rings, averaged over all levels.

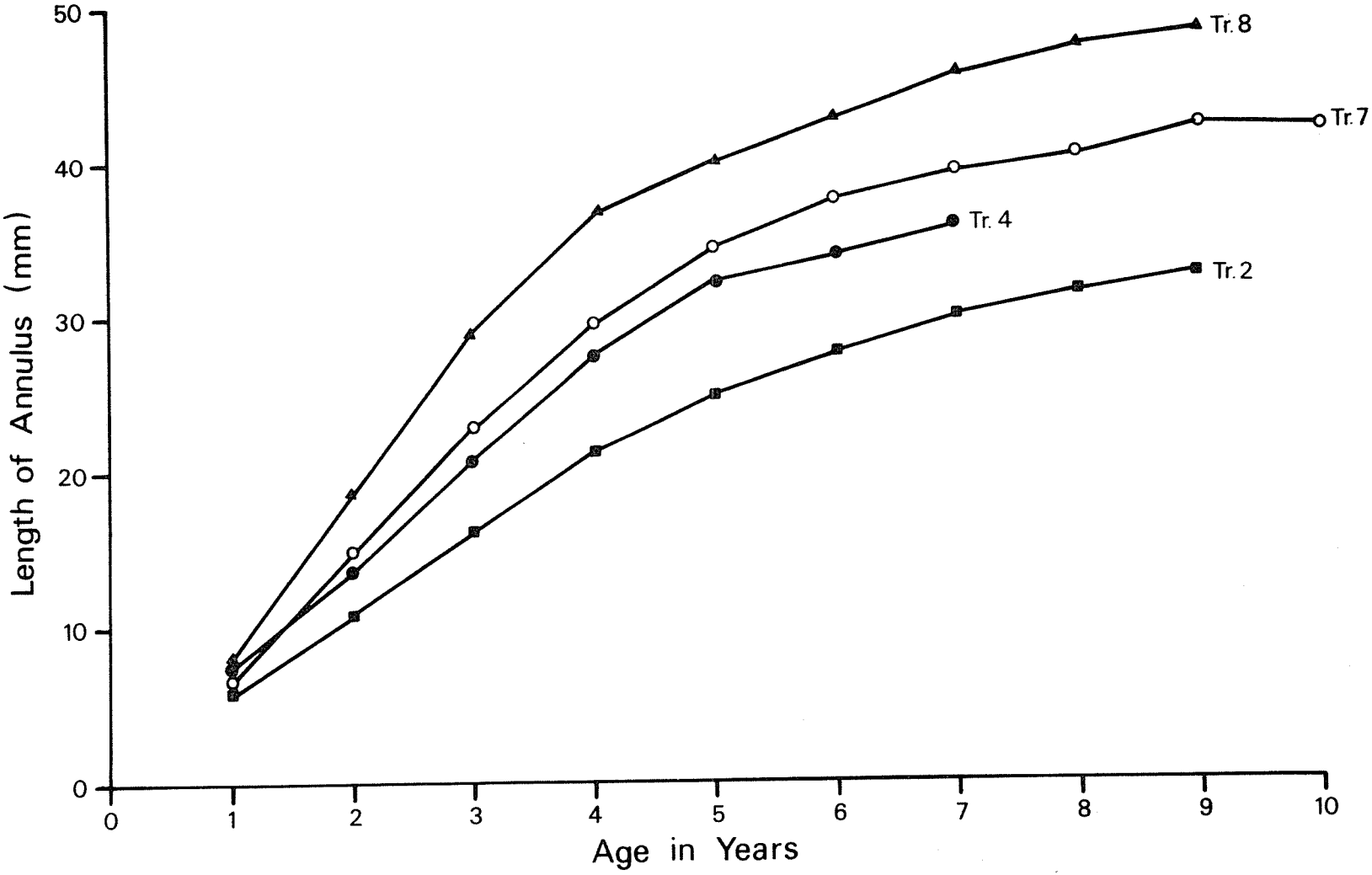


Fig. 7-22. Growth of *P. staminea* on 4 transects from measurements of annular rings at the -4 ft level.

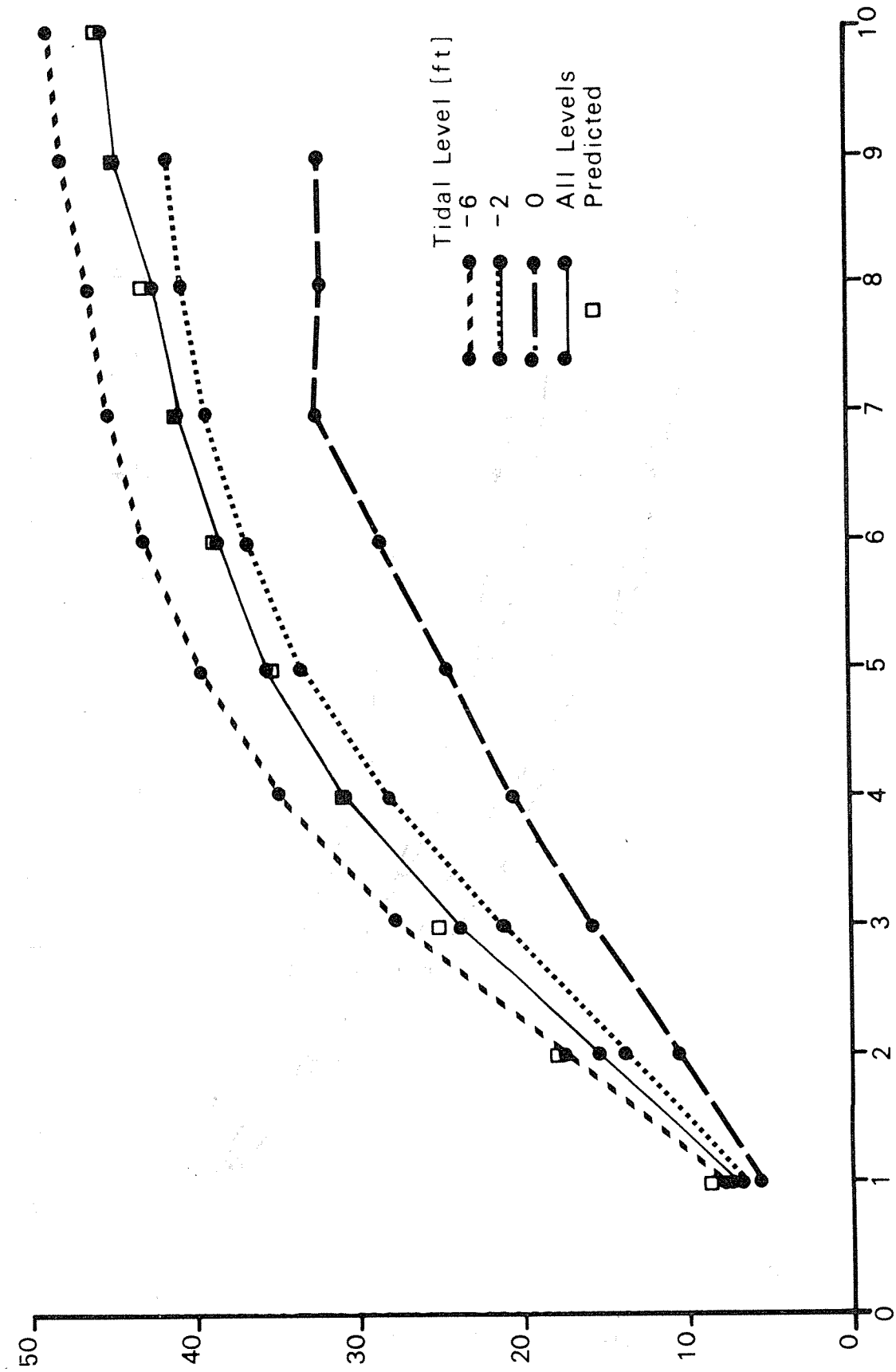


Fig. 7-23. Growth of *P. staminea* from measurements of annular rings. All transects and levels combined. Predicted L_t from von Bertalanffy growth equation and growth at 3 tidal levels averaged over all transects also shown.

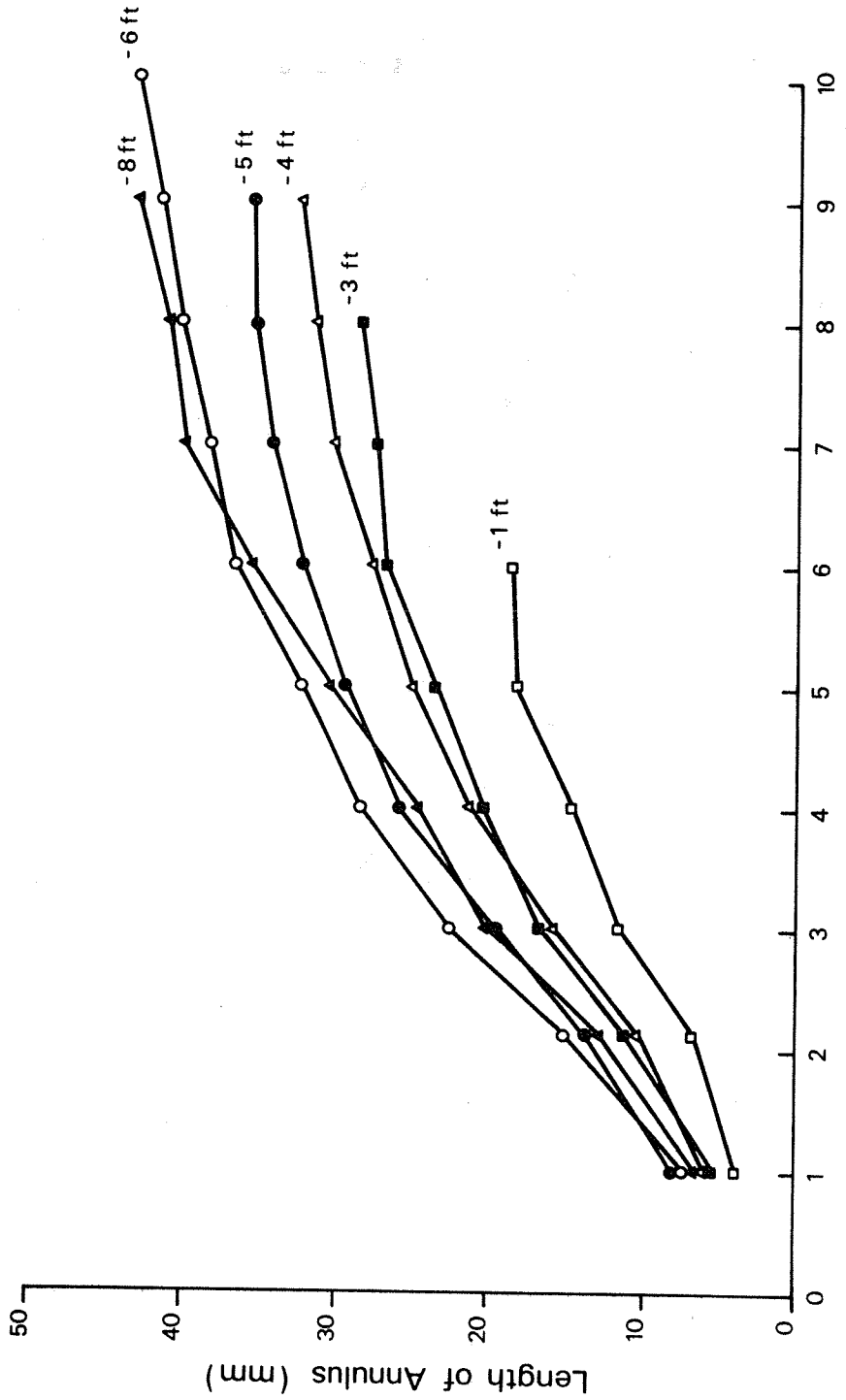


Fig. 7-24. Growth of *P. stamínea* at 6 tidal levels on transect 2 from measurement of annular rings.

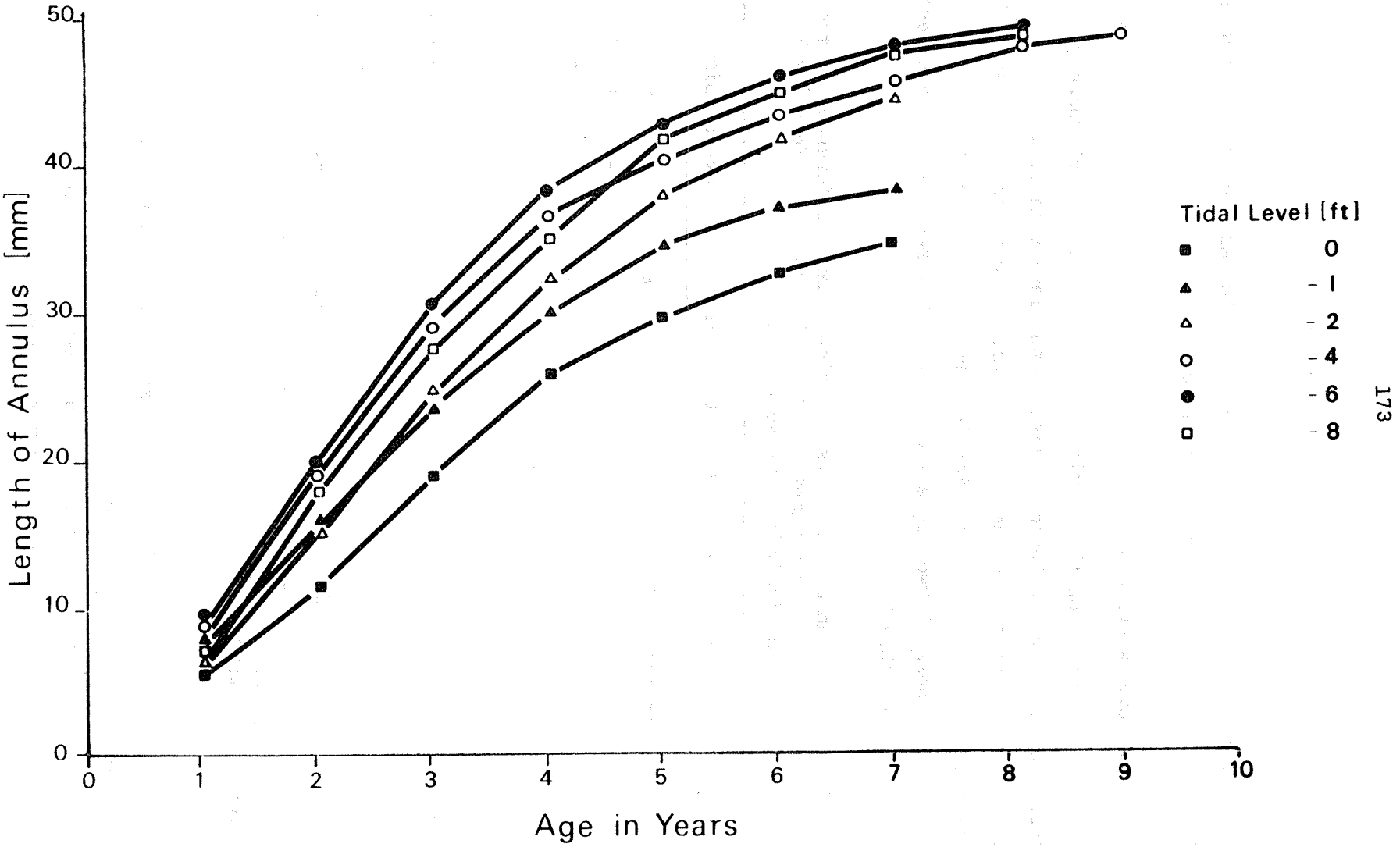


Fig. 7-25. Growth of *P. staminea* at 6 tidal levels on transect 8 from measurement of annular rings.

on the length at the start of the year (l_t) for each pair of measurements provided an estimate of K from the equation

$$\text{slope} = -(1-e^{-K}) \qquad (2)$$

L_∞ is the intercept on the X-axis (Fig. 7-26). Values of these growth parameters are listed for selected transects and levels in Table 7-3. The significance of differences between K's for various locations was tested through the t-test described by Steel and Torrie (1960, p. 173) for testing the homogeneity of the slopes of two regression lines. The results of these tests are summarized in Table 7-4.

Table 7-4. Summary of tests for significant differences in the growth parameter "K" for *P. staminea*. Tests based on individual measurements

	Transects	Levels	C.F.	Transects	Levels	Difference
Between transects	2	all		8	all	t = 6.9**
	2	-4		4	-4	t = 0.746 N.S.
	4	-4		7	-4	t = 2.39**
	7	-4		8	-4	t = 1.29*
	2	-4		8	-4	t = 3.7**
Between levels	2	-3		2	-6	t = -0.06 N.S.
	8	-2		8	-6	t = 4.09**
	8	-1		8	-4	t = 0.3 N.S.
	All	-2		All	-6	t = 1.18 N.S.

*Significant at 0.8 level.
**Significant at 0.95 level.
N.S. not significant

The growth rate of *P. staminea* was shown to be significantly lower on the south side of the Island (transects 2 and 4) than on the north (transects 7 and 8) when transects or specific tidal levels of transects on opposite sides were compared. On a given transect the trend was for increasing growth rate with decreasing tidal level through the -6-ft level. At the -8-ft level growth was generally slower than at the -6-ft level although data at this

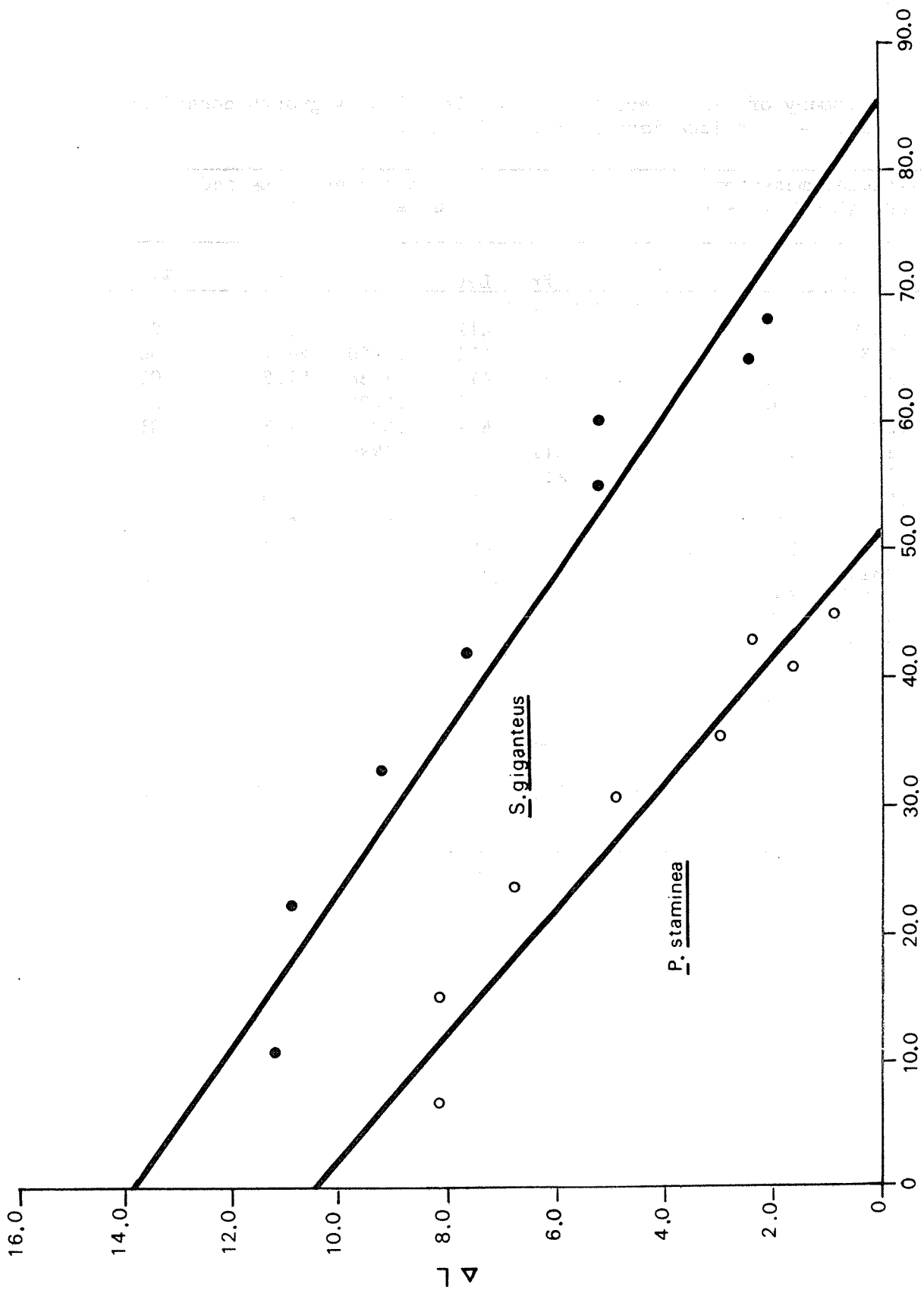


Fig. 7-26. Plots of average $\Delta L = L_{t+1} - L_t$ versus L_t for *P. staminea* and *S. giganteus* for all data.

Table 7-3. Summary of parameters in the von Bertalanffy growth equations for various locations at Kiket Island

From individual measurements of L_t and $\Delta L = L_{t+1} - L_t$					From averages of L_t and $\Delta L = L_{t+1} - L_t$				
Tr	Lev	K	L	t_o	Tr	Lev	K	L	t_o
				P. staminea					
2	A11	.1639	52.3		A11	A11	.2497	50.7	.24
2	-3	.2134	35.9		2	A11	.2020	44.4	.08
2	-4	.1381	49.5	.0004	4	A11	.1938	51.8	.01
2	-5	.1815	50.4		7	A11	.2235	52.9	.24
2	-6	.2095	52.4		8	A11	.3072	52.8	.31
2	-8	.1359	63.3		A11	-1	.1990	43.1	
8	A11	.2489	59.4		A11	-2	.1991	52.8	
8	-1	.2206	50.4		A11	-4	.2498	49.0	
8	-2	.1827	62.6		A11	-6	.2874	52.9	
8	-3	.1666	70.0		A11	-8	.2703	54.7	
8	-4	.2315	63.2	.44					
8	-5	.2630	59.2						
8	-6	.2740	58.7	.30					
8	-8	.2533	57.8						
4	-4	.1553	57.6						
7	-4	.2129	52.3	.09					
				S. giganteus					
A11	A11	.1429	96.66	.055	A11	A11	.1803	84.45	.22

lowest level were limited to those obtained from a relatively small sample on only three transects. Statistical proof of this apparent pattern of changing growth rates was not possible in most instances because of the low densities of clams at higher levels on all transects and at all levels on the south side transects. On transect 8 the growth rate at -2 ft proved significantly lower than that at -6 ft, but the distinction between growth at -1 ft and at -4 ft could not be proven.

Testing for differences between transects on the same side of the Island showed that the growth rates at -4 ft on transects 2 and 4 were not significantly different, again as a result of sample size. On the north side of the Island growth at -4 ft of transects 7 and 8 were significantly different at the .8 level only (Fig. 7-22).

A plot of the growth of each year class of *P. staminea* from 1961 to 1970 as backcalculated from the average length of each annulus for all clams in each age group is shown in Fig. 7-27. The samples from 1970 and 1971 provided two separate estimates for each point on the curves. For example, the mean length of the first annulus of the 1968 year class was 6.0 mm as estimated from the 2-year-olds taken in 1970 and 6.3 mm as estimated from the 3-year-olds taken in 1971. Lines drawn through the means of these two estimates trace the growth of each year class. The initiation of growth for each year class was arbitrarily set at approximately the beginning of May because the actual mean time of set in any year is not known. The values for the end of 1970 were estimated by only one point, that from the 1971 sample. The growth line anticipates the expected direction and deviation of the mean from this single point based on whether this last value was a continuation of the upper or lower of the two estimates from the previous year.

Horizontal dotted lines in Fig. 7-27 connect like annuli of several year classes to permit inspection of year-to-year variations of growth. These variations do not appear to be great in most years, although 1967 would seem to have been a better year for growth than 1968, particularly for the young of the year. Poor growth in 1968 seems to have caused a depression in the average size of both the 1967 and 1968 year classes as late as the end of 1969 even though growth conditions in that year were good, as indicated by the large size of the 1969 year class in their first winter.

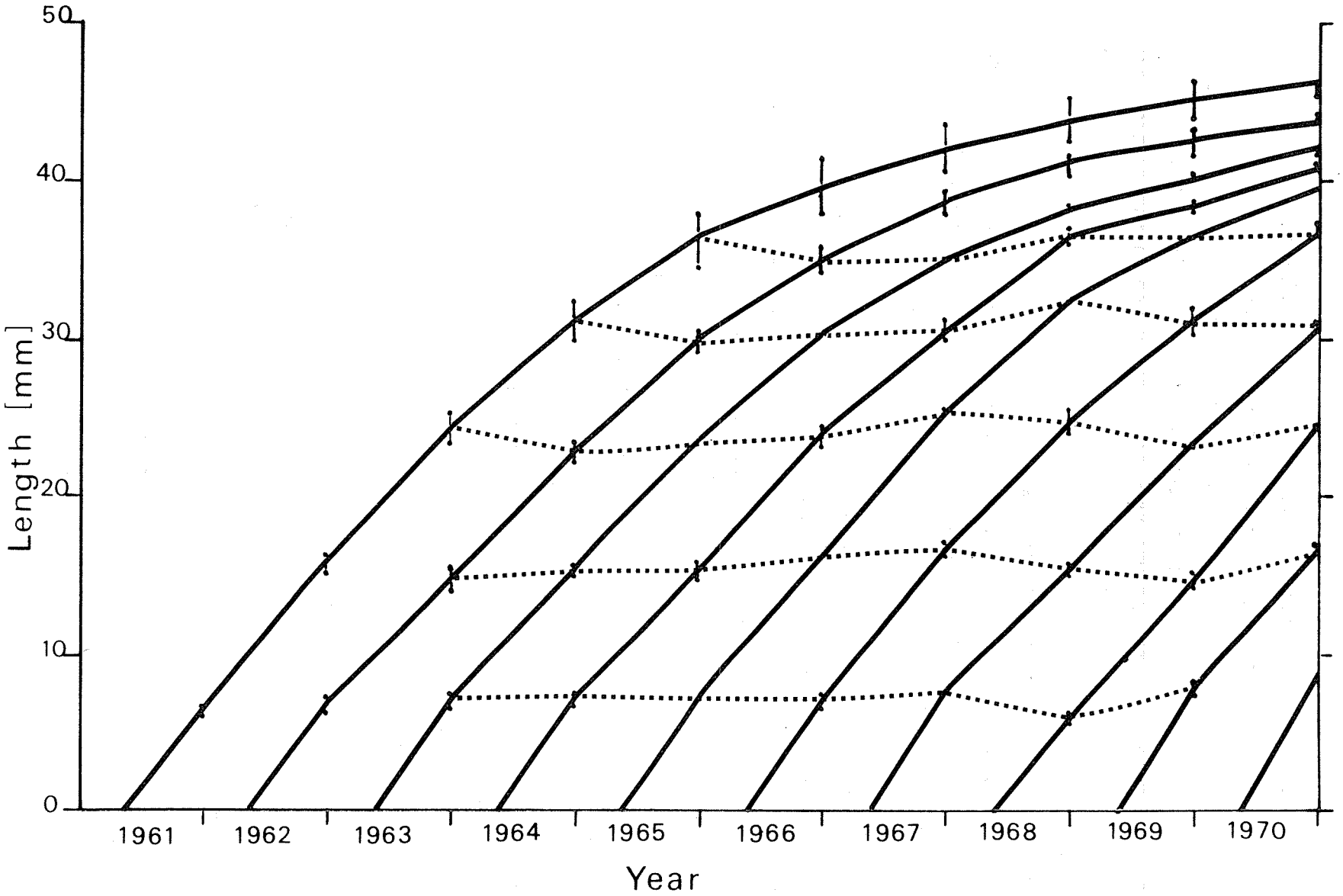


Fig. 7-27. Growth of 10 year classes of *P. staminea* from back measurement of annular rings for all data.

7.4.6.4 Production and Standing Crop

The annual production of a multi-aged unexploited population of a non-migratory species can be estimated by summing the change in biomass during the year for each cohort over all ages present. The change in biomass of a cohort is estimated by the product of the average weight gain per individual of age i and the average number of individuals of age i present during the year (Edmundson and Winberg, 1971).

The average weight gain per individual of each age is easily obtained from a von Bertalanffy growth curve (Fig. 7-28A) that has been transformed by the use of an appropriate length-weight relation to the form

$$\overline{Wt}_t = W_\infty \left(1-e^{-K(t-t_o)}\right)^n \qquad (3)$$

where W_∞ = asymptotic weight corresponding to the asymptotic Length, L_∞,

$\overline{Wt}_t$ = average weight at time t,

and n = 3 for species where weight is proportional to the cube of length.

To obtain weights for use in production figures the equation was derived from a Ford-Walford type regression of the average L_{t+1} on the average L_t which was found to give a better fit with the actual data than the equation derived from the individual values.

The length-weight ratio of *P. staminea* at Kiket Island ranged from $W_t = 0.0030\ L^3$ to $W_t = .00033L^3$ for several locations with populations at lower tidal levels tending toward the latter equation. For the Island as a whole (all clams from beach sampling) the figure was $W_t = .0032\ L^3$.

To determine the average number of clams in each cohort during the year, we found it necessary to obtain some estimate of the number of clams of each cohort present at some time during the year and correct that figure using an estimate of the mortality rate for that cohort. For each location there were two estimates available in each year of the number of clams present. The estimate from the winter series of sampling was considered to be unaffected

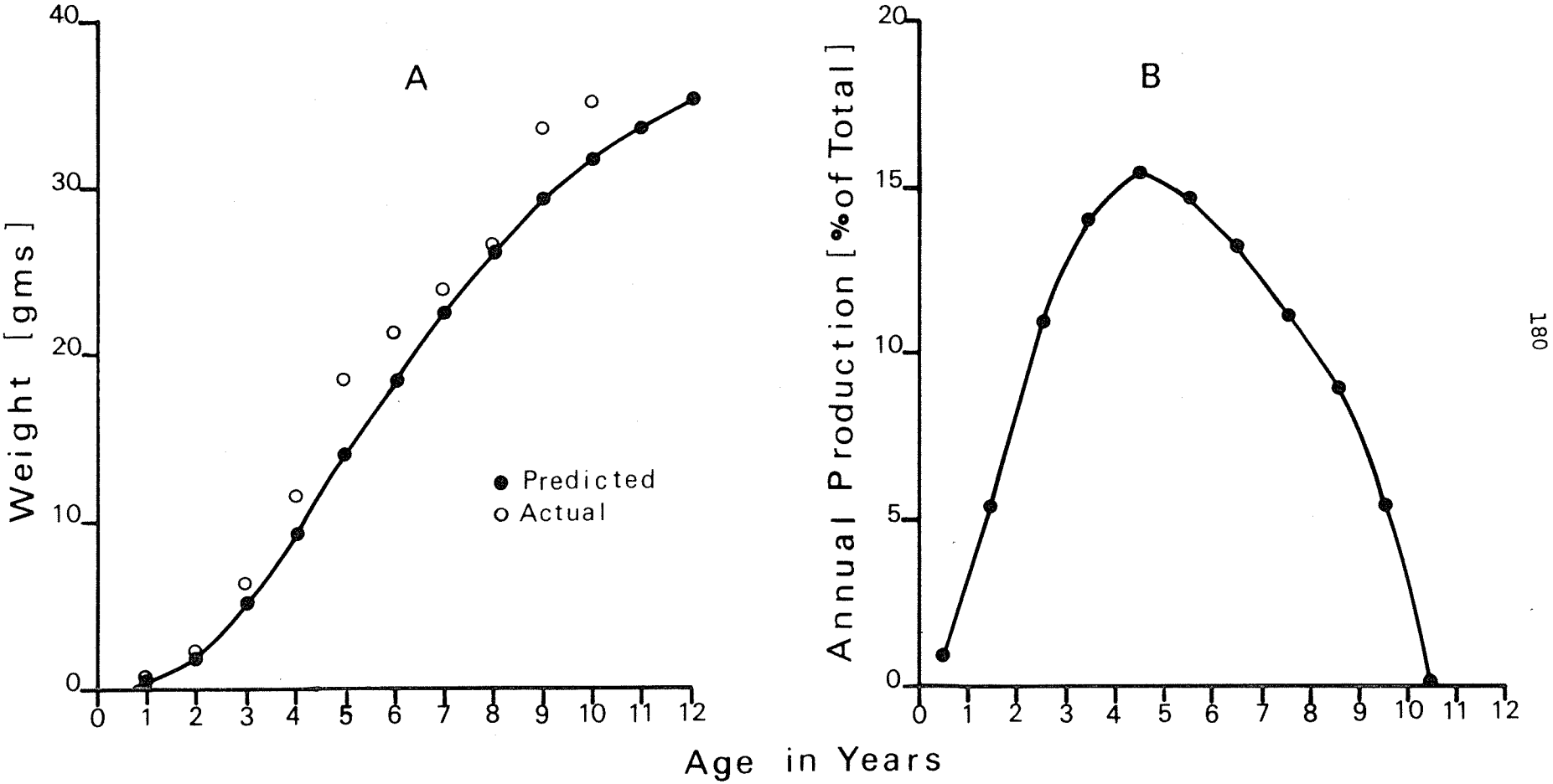


Fig. 7-28. A. Predicted and actual mean weight of *P. staminea* from all samples. Actual values are averages from samples taken at various times throughout the year.
B. Theoretical annual production of *P. staminea* as a function of age. Based on smoothed growth and survivorship curves for all data.

by mortality in that year or, effectively, the number at the beginning of the year. The summer series of sampling was done largely during the month of July, and the estimated density at this time was considered to be the average for the year, i.e., one-half of the expected mortality for the year was assumed to have occurred by the time of sampling. To reduce data analysis costs, we did not compile the age frequencies separately for each season of sampling at each level. Therefore, to obtain an estimate of the average number of each cohort present, we assumed one-half of the total number of that cohort taken at that location to have been taken in the winter sampling, that is, we considered age structure as constant from winter to summer. Thus, for all the clams of age i at a given location the mortality rate was considered to be acting on one-half of them for one-half year and not at all on the other half (since they were taken at midyear).

The estimation of mortality rates was complicated by several factors. Normally, three or four successive samples of a population would provide data on the declining numbers of each cohort so that a mortality rate for that cohort could be calculated. Because we altered the sampling pattern at Kiket Island after the first year to increase the detail in descriptions of animal distributions, the four samples taken (two winter, two summer) were not equivalent samples. A plot of age-frequency distribution of all *P. staminea* taken in each of the two years (with seasons combined) with the horizontal axes offset to line up year classes is shown in Fig. 7-29. Although the shapes of the distributions are similar and strong year classes in 1963, 1964, and 1967 can be identified, it is obvious that these data cannot be used for a calculation of mortality rate because in some year classes there were more clams taken in 1971 than in 1970. When individual transects or levels where sampling effort was constant over the four periods (e.g., transect 7) were examined (Fig. 7-30), the sample size was found not large enough to overcome statistical sampling errors or vagaries of patchy spatfall. Furthermore, it would have been desirable to have taken several samples yearly, not semi-annually.

Because of these shortcomings in the experimental design and longevity of the studies at Kiket Island, a procedure was devised for estimating mortality which has limitations but which seemed to be the best available.

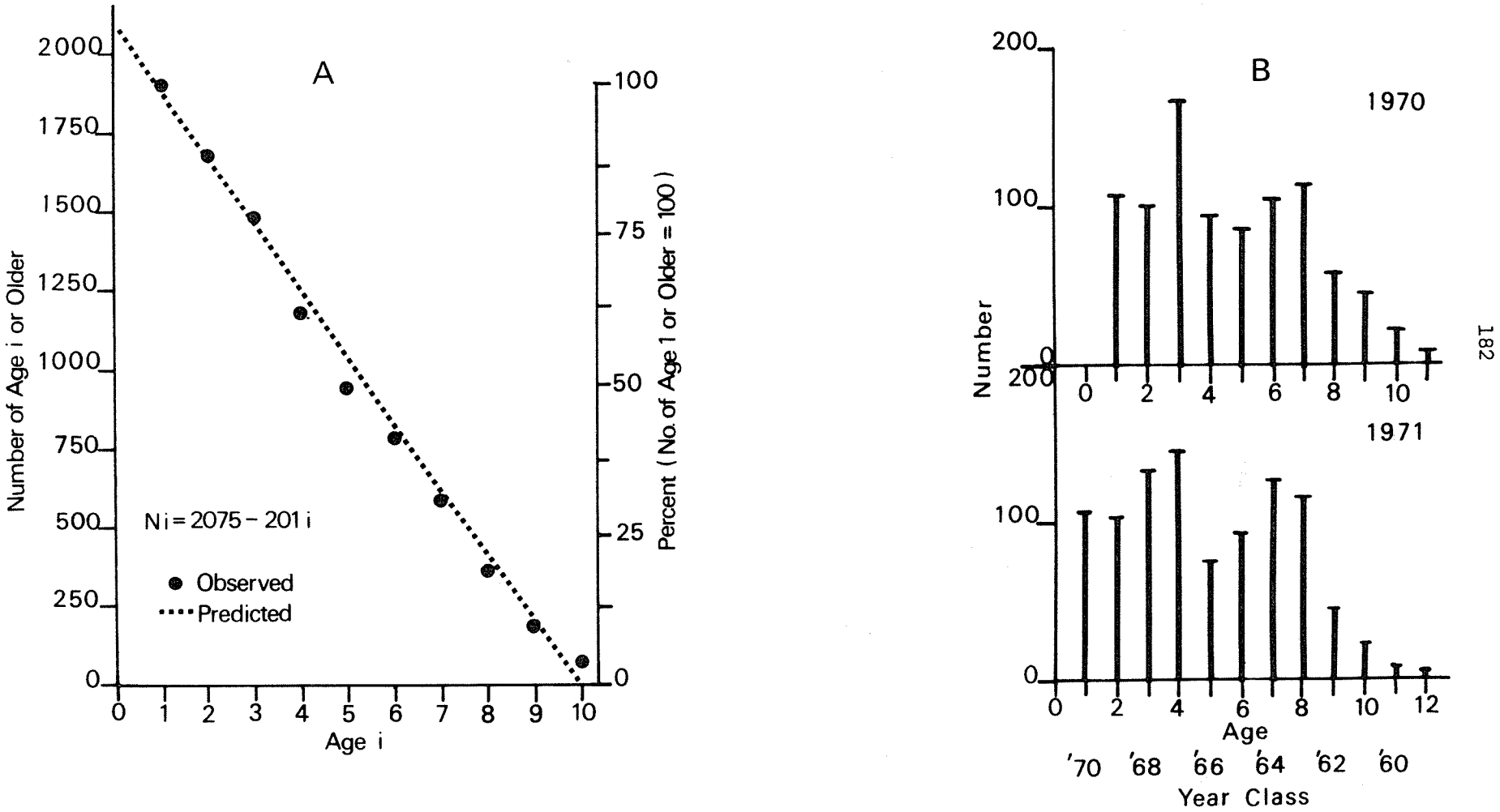


Fig. 7-29. Arithmetic cumulative survivorship curve (A) and age-frequency distribution (B) for *P. staminea* for all data.

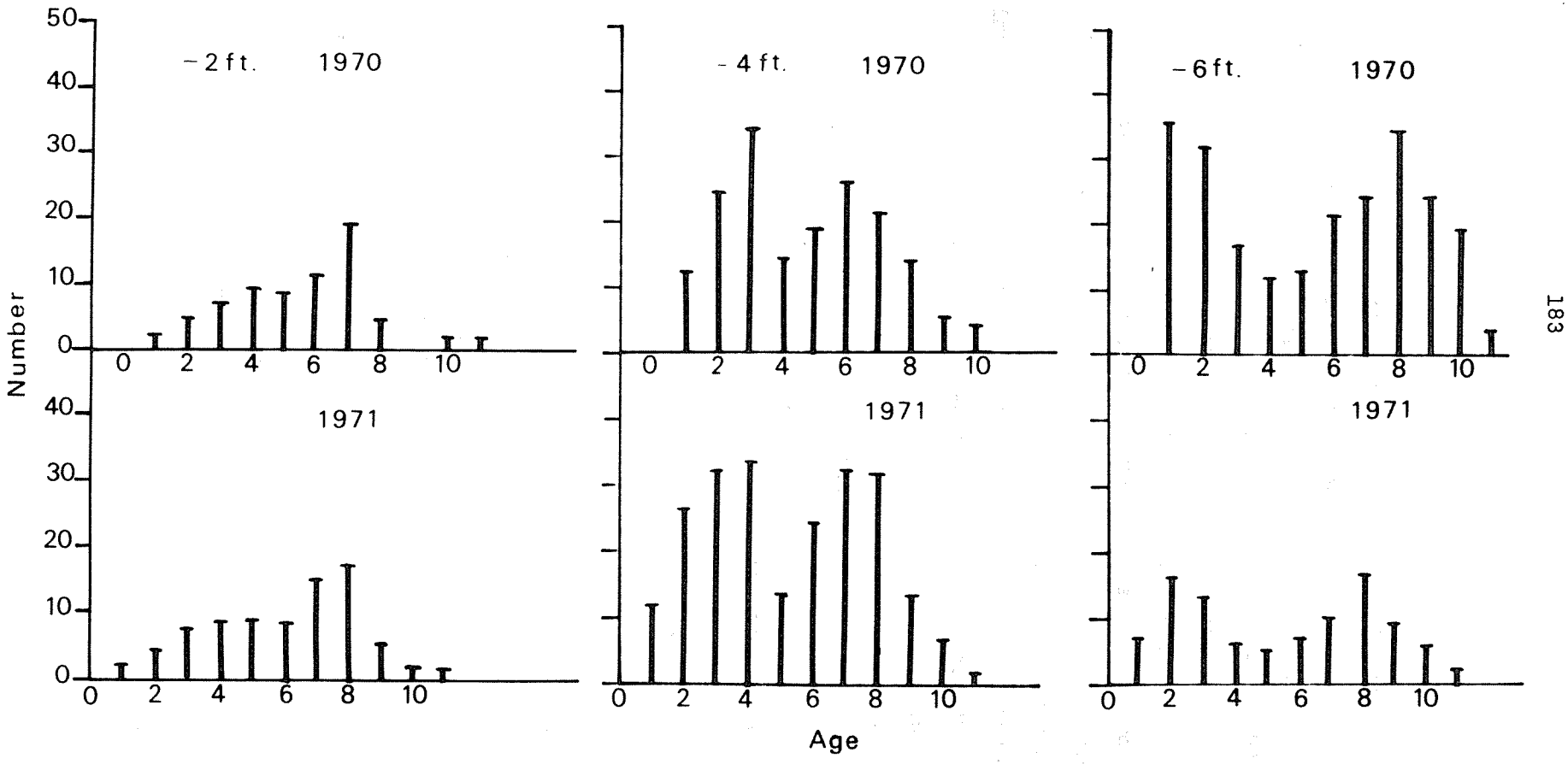


Fig. 7-30. Age-frequency distributions of *P. staminea* at three tidal levels on transect 7.

Taking the number of clams of age 1 or older as 100 per cent of clams fully recruited to the sampling techniques employed, we made a plot of the percentage of this number of clams age 2 or older, the percentage of age 3 or older, and so on (Fig. 7-31). Although not a true survivorship curve following a single cohort through time, it may be treated as such with some reservations. First, the assumption has been made that recruitment is constant from year to year. Although the histogram of age frequency for all sampling (Fig. 7-29) shows a coincidentally identical number of one-year-olds in 1970 and in 1971, there are strong indications in older year classes that this is not always the case. However, the assumption of constant recruitment is commonly made in production estimates that are intended to be the average expected production for average conditions.

Secondly, the actual mortality rates of each successive cohort are assumed to be constant for a given year of life. The same arguments are applicable here as above. Certainly this assumption is not strictly true, but on the average it should not cause gross errors. What is created in this plot, then, is a "cumulative survivorship" curve representing the average recruitment and mortality over a varying number of years for each point. The point for age 2 includes all two-year-olds having survived from an initial recruitment through two years of mortality, all three-year-olds having survived from recruitment through three years of mortality, etc. The fact that the curve is relatively smooth attests to the suitability of averaging in this manner. This type of procedure is suggested by Gulland (1969) as one means of estimating total mortality coefficients. Separate semilog plots of cumulative survivorship for 1970 and 1971 (Fig. 7-31A) are of similar shape, but by averaging these two estimates (Fig. 7-31B), one can achieve additional smoothing.

The shape of the logarithmic survivorship curve for exploited fish populations is typically linear (Gulland, 1969) as a result of a constant mortality rate (Z) where the number present at time t is related to the initial number by the equation

$$N_t = N_o \, e^{-Zt} \qquad (4)$$

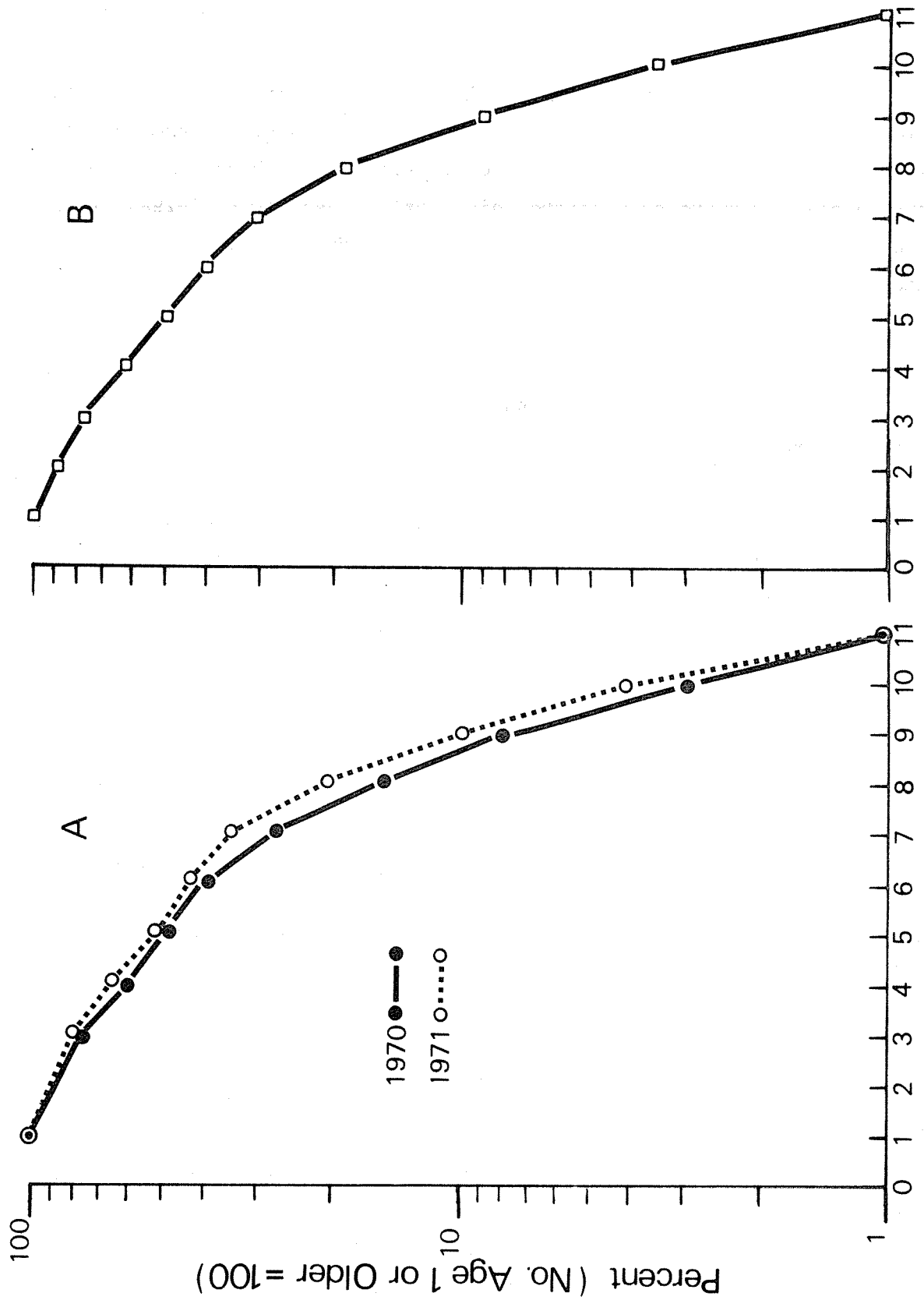


Fig. 7-31. Logarithmic cumulative survivorship curves for *P. staminea* in 1970 and 1971 separately (A), and combined (B). Number of age 1 and older clams = 100 per cent.

Figs. 7-31A and 7-31B are obviously not linear, indicating that the mortality rate was not constant but rather increasing with age. This conclusion is evident in Fig. 7-32A, which is a plot of Z versus age. When graphed on an arithmetic scale survivorship becomes distinctly linear (Fig. 7-29A) except for age 10 and above. The equation of this line (fitted with FRD 312 Linear Regression Program) is

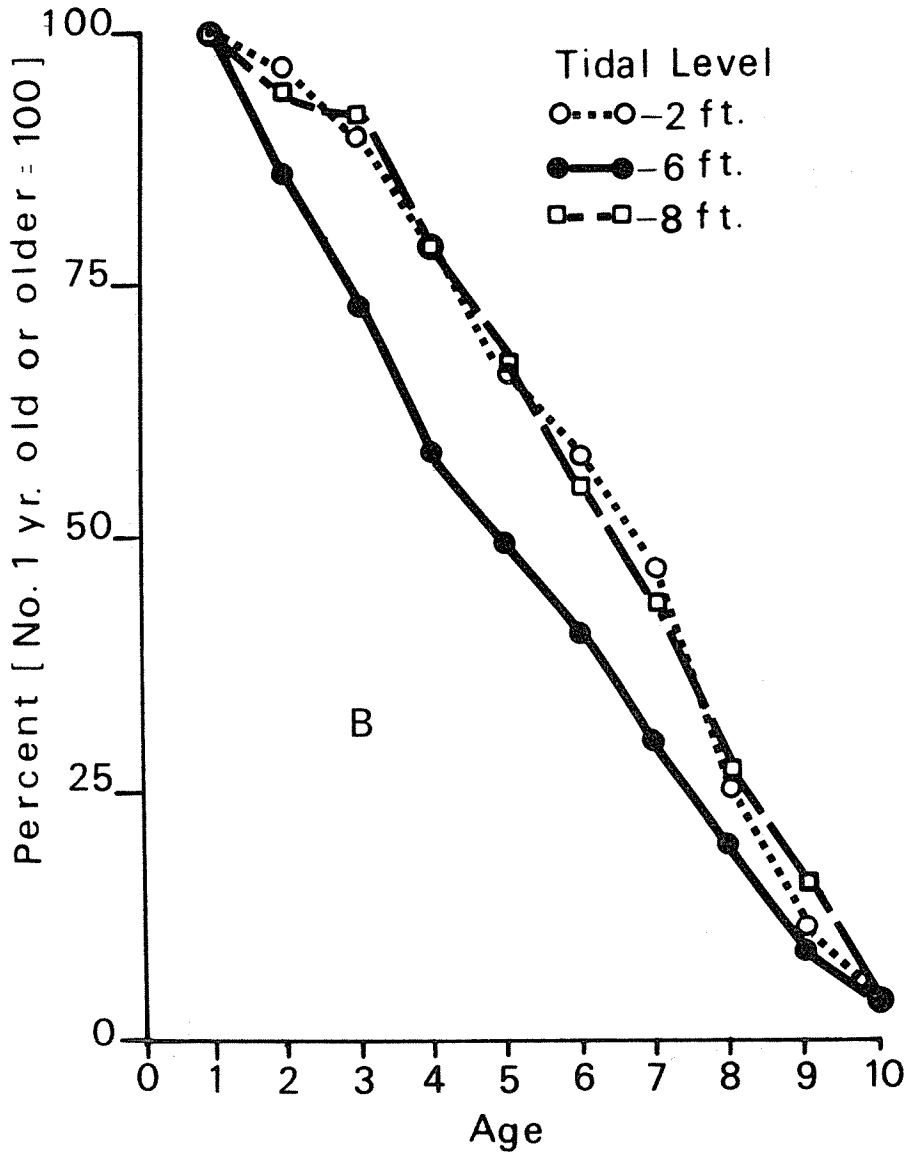
$$N_t = 2075\text{-}210t \qquad (5)$$

$$(r^2 = 0.99; \quad F_{(1,8)} = 1151^{**})$$

The remarkable conclusion is, then, that equation 4 does not apply and that a constant number of clams is lost each year! For earlier years the fit is very close, but for older clams ($i > 10$) it cannot apply because it predicts that none survive after nine years. As a result of this apparent anomaly in the mortality pattern of *P. staminea* relative to that of other fish stocks, classical methods for calculation of production had to be modified somewhat.

The average number of clams in each cohort present during the year was based on the initial number (n_i) taken from the predicted year class strength on the survivorship curve and modified by a survivorship factor ($\bar{S}_i$) derived from the predicted cumulative numbers of clams of age i or older (N_i) and age i + 1 or older (N_{i+1}). Note that N_i is the cumulative number (N_i and older) from the survivorship curve, whereas n_i refers to the number assumed to be present in the i^{th} age class at the start of a given year.

Since the arithmetic survivorship curve is linear, the average fraction of the initial number in each cohort present over the year is the ratio of the number surviving at t = i+1/2 to the initial number or $\frac{N_{i+1} + N_i}{2N_i}$. Since one half of the total sample at any one location was assumed to have been taken at the start of the year (the winter series), and the remaining half (the summer series) was assumed to have already suffered one-half of the year's expected mortality, the average fraction of each cohort present during the year for the purpose of production calculations should be



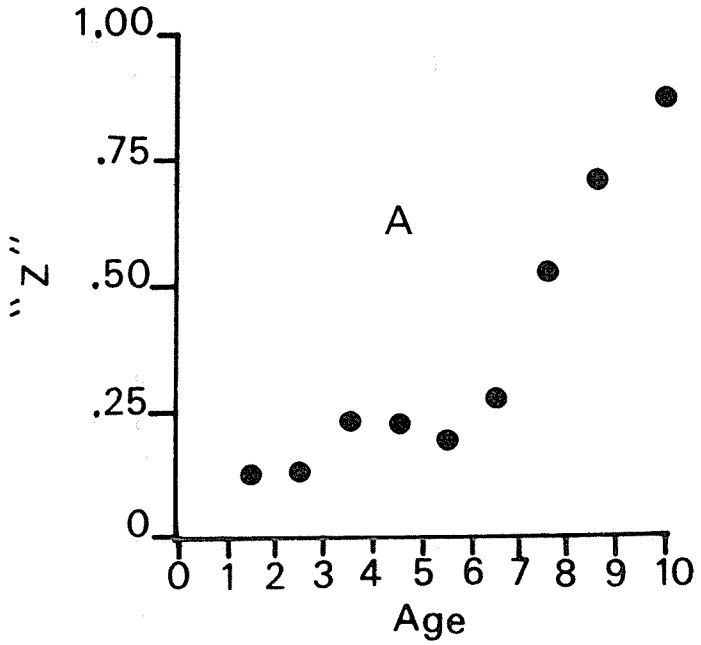


Fig. 7-32. A. Mortality coefficient (Z) of *P. staminea* as a function of age for all data.
B. Arithmetic cumulative survivorship curves for *P. staminea* at 3 tidal levels, averaged over all transects.

$$\frac{N_{i+1} + N_i}{4N_i} + 1/2 = \overline{S}_i \qquad (6)$$

The average production of the i^{th} cohort is then

$$\overline{P}_i = \overline{S}_i \cdot n_i \cdot \overline{Wt}_i \qquad (7)$$

where $\overline{Wt}_t = \overline{Wt}_{t+1} - \overline{Wt}_i$ from equation 3 with t = i.

The production of the zero age class could not be directly calculated in this manner because of deficiencies in sampling. These clams were generally smaller than the mesh size (7 mm) of the screen used for sieving the sample quadrats (though not that used for the cores). They were also poorly represented in the summer series of samples by virtue of their setting from June to September (Quayle, 1943). By the time of the winter series they were counted as age 1. Therefore, the number of age 0 clams setting was estimated by extrapolation of the arithmetic survivorship curve (Fig. 7-29A) to t = 1/2. Because of an expected higher rate of mortality for the newly set clams, this figure was taken as the average number present during the year (n_o) even though obviously none were present in the early part of the year. Despite this apparently liberal assumption, the production of this cohort (Fig. 7-28B) was always less than 1 per cent of the total average production ($\overline{P}$), which was calculated by

$$\overline{P} = \frac{\sum_{i=0}^{i_{max}} \overline{P}_i}{Q} \qquad (8)$$

where i_{max} = maximum age reached, and

Q = number of quadrats sampled in area in question.

Units are grams wet weight of *P. staminea*, shell included, produced per $0.25m^2$ per year.

Not accounted for in these calculations were the sex products, discharged annually by mature clams. It was estimated that these would amount to only a few per cent of the total wet weight including the shell, on which the calculations were based.

Before the method of production calculation described above was applied to specific locations, we constructed cumulative survivorship curves for certain groups of data to test whether or not there were differences between areas. Differences did indeed occur with survivorship on the north side (transects 6-8) somewhat higher than on the south side (transects 1-5). Fig. 7-32B demonstrates that survivorship was higher and remarkably similar at -2 and -8 ft compared to -6 ft, where maximum growth was found and where conditions would be expected to be optimum for survival as well. Because of these variations, calculations of average production for specific localities were based on cumulative survivorship curves and on von Bertalanffy growth curves for those locations.

Thus, all factors in this calculation were taken from smoothed curves fitted to the raw data. When similar figures were obtained from the unsmoothed data, e.g., for production of the entire intertidal, the error was less than 4 per cent. Because of the laborious nature of these calculations, even with the aid of computers, we did not obtain figures for all possible transects and levels, but only for sufficient subgroupings to establish the general patterns about the Island.

At each location where production was calculated, the standing crop could also be obtained as the product of average clam density (clams/.25 m^2) and average weight(g/clam). Since each of these factors had a known variance, the variance of the standing crop (average g total weight/0.25 m^2) was readily obtainable by the delta method. However, the variance of the average weight was high since weights of all ages were averaged. Thus, the average standing crop was obtained by the alternate method of averaging separate calculations for each quadrat sampled in the area in question and taking the variance of this mean. This procedure, in effect, removed the readily explainable variance in the mean weight of clams of many ages and was hence a more accurate estimation of the standing crop.

The variance of the estimation of production at any location involves such a multitude of factors as to be virtually impossible to obtain. However, some idea of the confidence limits placed on the production estimation may be obtained from the variability of the standing crop estimate and the ratios of standing crop to production obtained for several locations. These figures are summarized in Table 7-5.

Table 7-5. Summary of calculations of production and standing crop of *P. staminea* at various locations

Transect(s)	Level(s) (ft)	S.C. ($g/.25m^2$)	n	Variance	Standard error	95% Confidence ($\pm g/.25m^2$)	95% Confidence (± per cent)	$\bar{P}$[1] ($g/.25m^2$-yr)	$\frac{S.C.}{\bar{P}}$	Approximate area m^2	S.C. total kg	$\bar{P}$ total kg/yr
All												
(2,4,7,8)	0-2-4-6	123.2	175	36,328	14.4	28.8	23	23.7	5.2	42,300	1,303	250.6
(2,4,7,8)	-2-4-6	153.5	140	40,822	17.1	34.2	22					
South side												
(2,4)	0-2-4-6	17.9	93	841	3.0	6.0	34	4.34	4.1	24,300	109	26.4
(2,4)	-2-4-6	23.1	72	968	3.7	7.4	32					
North side												
(7,8)	0-2-4-6	242.6	82	49,926	24.7	49.4	20	45.6	5.3	18,000	1,092	205.2
(7,8)	-2-4-6	291.6	68	46,028	26.0	52.0	18					
2	0-2-4-6	19.4	48	1,022	4.6	9.2	47	4.07	4.8			
	-6	48.2	12	2,230	13.6	27.2	56					
	-4	28.5	12	344	5.4	10.8	38					
	-2	0.9	12	9.1	0.9	1.8	100					
4	0-2-4-6	16.2	45	662	3.8	7.6	47	4.6	3.5			
	-6	28.3	12	2,142	13.4	26.8	95					
	-4	26.0	12	704	7.7	15.4	59					
	-2	6.8	12	90	2.7	5.4	79					
7	0-2-4-6	306.3	43	57,917	36.7	73.4	24	62.5	4.9			
	-6	460.4	12	67,881	75.2	150.4	33					
	-4	450.3	12	25,062	45.7	91.4	20					
	-2	184.8	12	5,441	21.3	42.6	23					
	0	3.6	7	31	2.1	4.2	100					
8	0-2-4-6	172.2	39	32,731	29.0	58.0	34	35.1	4.9			
	-6	389.4	12	25,496	46.1	92.2	24					
	-4	133.2	11	4,522	20.3	40.6	30					
	-2	660.5	9	3,261	19.0	38.0	63					
	-1	41.5	6	2,333	19.7	39.4	95					
	0	4.9	7	171	4.9	9.8	100					

[1] Based on all samples 0 ft to -8 ft less those from areas of near solid rock.

The standing crop of *P. staminea* in beach areas above mean sea level was negligible in all areas and was insignificant above -2 ft on the majority of the south side of the Island. One exception to this was the vicinity of transect 5, where the rock bench underlying shallow sediments apparently trapped sufficient water to allow moderate numbers to survive at the 0-ft level. A few were as high as the +1-ft level, the highest occurrence of this species found in the study.

The production and standing crop on the south side of the Island excluding the transect 5 area were extremely poor, 4.34 g/.0.25 m^2 yr and 17.9 ±6.0 g/0.25 m^2 respectively (ratio 4.1), based on samples from 0, -2, -4, and -6 ft. In contrast, on the north side the comparable figures were 45.6 g/0.25 m^2-yr and 242.6 ± 49.3 g/0.25 m^2 (ratio 5.3). For the entire Island the means for the area below mean sea level were 23.7 g/0.25 m^2-yr and 138.1 ± 31.6 g/0.25 m^2. The peaks of both standing crop and production were at -4 and -6 ft on transect 7 and this transect on the whole had the greatest production of any transect.

The total standing crop of *P. staminea* in the area from mean sea level to the -6-ft contour was estimated at 1303 kg and the total annual production in the same area at 250.6 kg. For the south side of the Island the estimates were 109 kg standing crop and 26.4 kg/yr production, whereas for the north side they were 1092 kg standing crop and 205.2 kg/yr production although it had 26 per cent less area. Too few samples were taken below -6 ft for standing crop to be estimated accurately in this area, but if the average value from the -6 ft-level (based on transects 2, 4, 7, 8) is assumed to be a reasonable approximation of the standing crop throughout the area from -6 to -8 ft, then the total standing crop in this region was 1916 kg. Since Fig. 7-33B shows a decreasing density of *P. staminea* below -6 ft, this may be a liberal estimate unless the true peak is somewhat below the -6-ft level. The grand total estimate for standing crop between mean sea level and the -8-ft contour becomes 3219 kg.

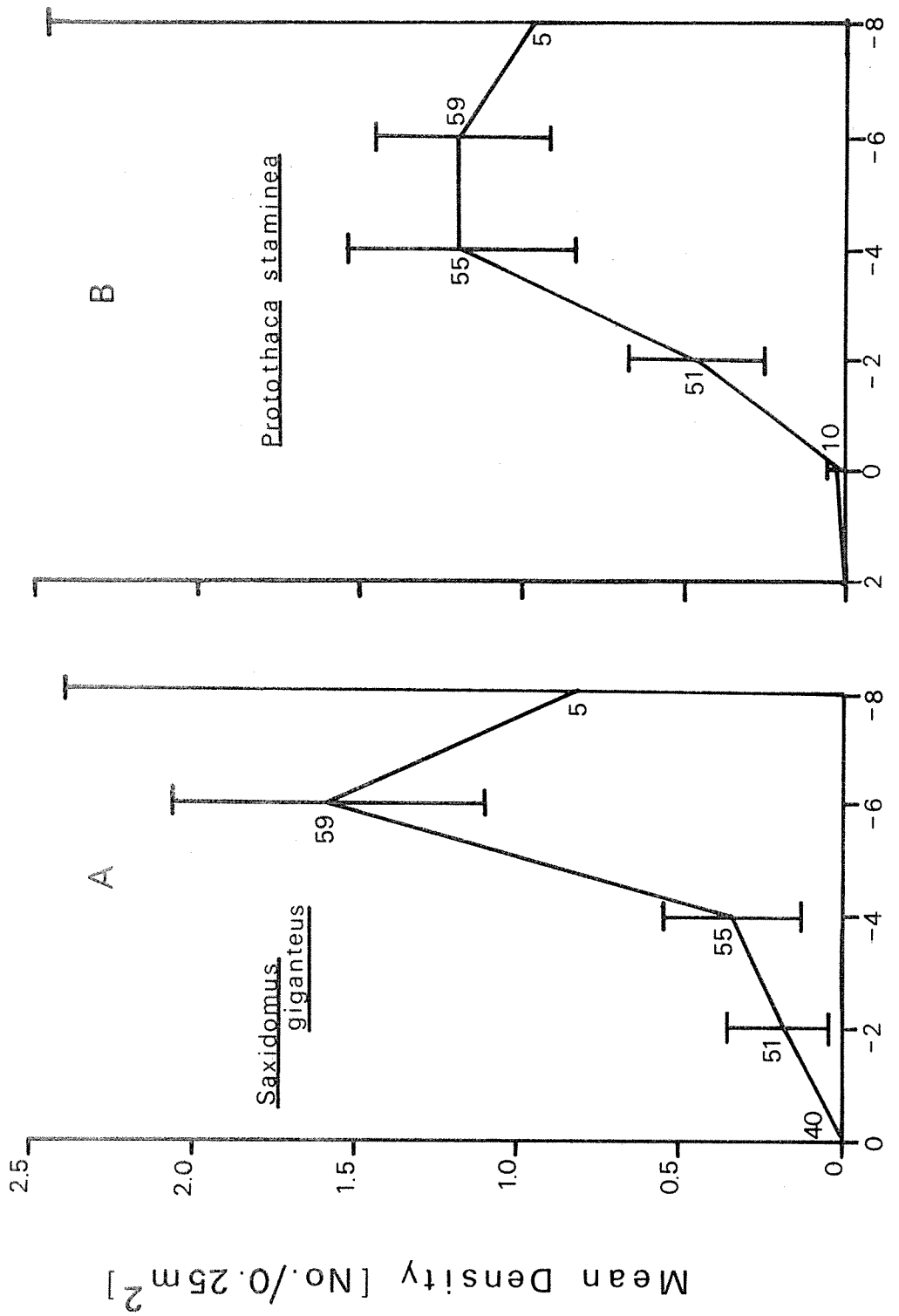


Fig. 7-33. A. Vertical distribution of *S. giganteus* averaged over transects 2, 4, 6, 7, and 8.
B. Vertical distribution of *P. staminea* averaged over transects 2, 4, 6, 7, and 8.
(Numbers adjacent to data points are number of samples on which figures are based.)

7.4.7 Distribution, Age, Growth, and Production of *Saxidomus giganteus*

The same techniques of sampling, ageing and calculation of growth rates, survivorship, production and standing crop described in the previous section were also applied to the butter clam, *Saxidomus giganteus*.

7.4.7.1 Distribution

The butter clam, *Saxidomus giganteus*, was found in significant numbers only below the -4-ft level (Fig. 7-33A). The peak in density was observed at -6 ft on all transects except #6, where the one sample from -8 ft contained 3 individuals. Numbers definitely increased below -6 ft and probably peaked at about -7 ft along the north side of the Island. The lower value in Fig. 77-33A at -8 ft may reflect decreasing numbers or may be an artifact of the relatively few samples taken at that level. Transect 7 had the highest density of this species averaged over two years. *S. giganteus* did well at lower tidal levels in association with *P. staminea* in silty mixed sand, gravel, and cobble (e.g., transect 7), but the highest density in a single sample was in relatively clean sand with cobble at transect 4.

7.4.7.2 Age Determination

We took insufficient numbers of this species in the monthly sampling during 1972 to apply the same quantitative techniques used with *P. staminea* for establishment of the validity of age determination from the distinct checks in shell sculpture. However, the few taken did show the same progressive increase in new growth during the summer and no abnormally small values of "ΔL," which would indicate the presence of an extraneous check. Those replanted without marking at the end of May formed generally more distinct disturbance checks than *P. staminea* did, possibly because conditions of replanting were less favorable for the larger species. All clams were covered with about 2 inches of gravel when left in May, but the *Saxidomus* were all from 4 to 8 inches deep when recovered in early November; thus, considerable energy had been required to dig through the coarse sediments to reach the desired depth. Growth from the time of planting in several individuals was directed somewhat inward and produced a break in the smooth profile of the shell. In others, concentric

growth lines were irregular and one individual formed a rather distinct false check subsequent to the disturbance check at time of initial handling. Even though these results indicate that *S. giganteus* is more likely to form disturbance checks than *P. staminea*, it was felt that age determination from annular rings was reliable for the younger clams at least, but decreased in accuracy for clams greater than 8 yr old. Analysis was based on measurements of 141 individuals, several of which were estimated to be over 12 yr old.

7.4.7.3 Growth

The growth of *S. giganteus* as determined from the mean length of each annulus is plotted in Fig. 7-34. As in the case of *P. staminea*, growth tended to increase from transect 2, to 4, to 7, and growth was better at lower tidal levels than upper. At transect 8 too few were found for a growth curve to be constructed. The values for length at each age predicted from the von Bertalanffy growth equation for all data are also shown in Fig. 7-34. They display a remarkably close fit to the measured data.

An arithmetic plot of cumulative survivorship for all *Saxidomus* taken in the study is shown in Fig. 7-35A. The equation of the fitted line from which numbers in each age class were obtained for production calculations is

$$N_t = 131.4 - 9.8\ t \qquad (9)$$

$$(r^2 = 9.9;\ F_{1,11}) = 815^{**})$$

Again the fit is excellent, as with equation 5 for *P. staminea*, but the plot of the total mortality coefficient (Z) with age (Fig. 7-35B) appears relatively constant through age 6 and increases erratically thereafter. This may have been the result of the small sample size or of improper interpretation of annuli on older individuals, although it matches the pattern of mortality in *Anodonta anatina* found by Negus (1966).

7.4.7.4 Production and Standing Crop

At any rate, calculations of production and standing crop were made from the predicted numbers from the linear arithmetic survivorship curve. Predicted weights were derived from lengths at each age on the von Bertalanffy growth curve converted by the derived length-weight relation $W_t = .00028L_t^3$.

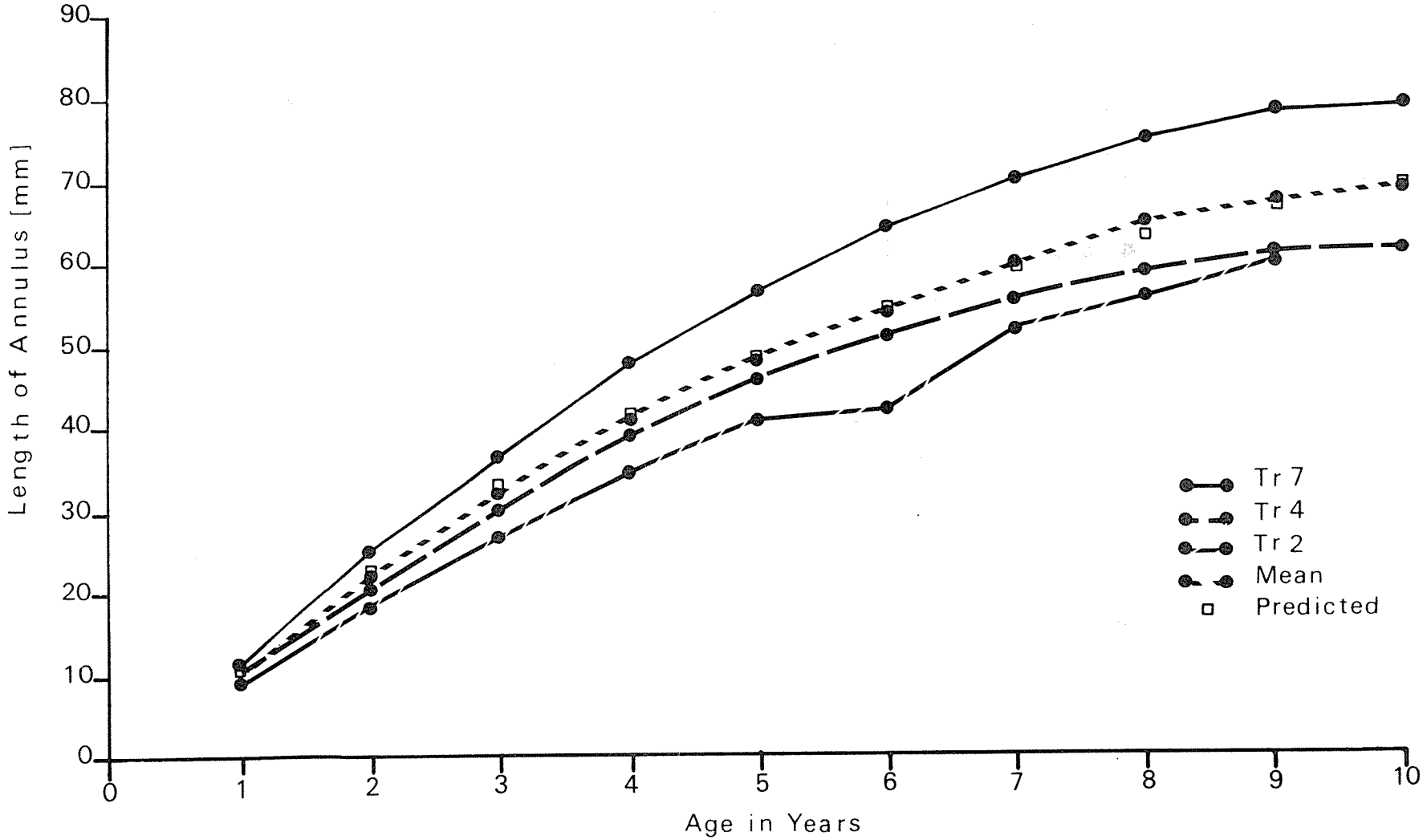


Fig. 7-34. Growth of *S. giganteus* on 3 transects from measurements of annular rings and averaged over all levels. Predicted L_t from von Bertalanffy growth equation included.

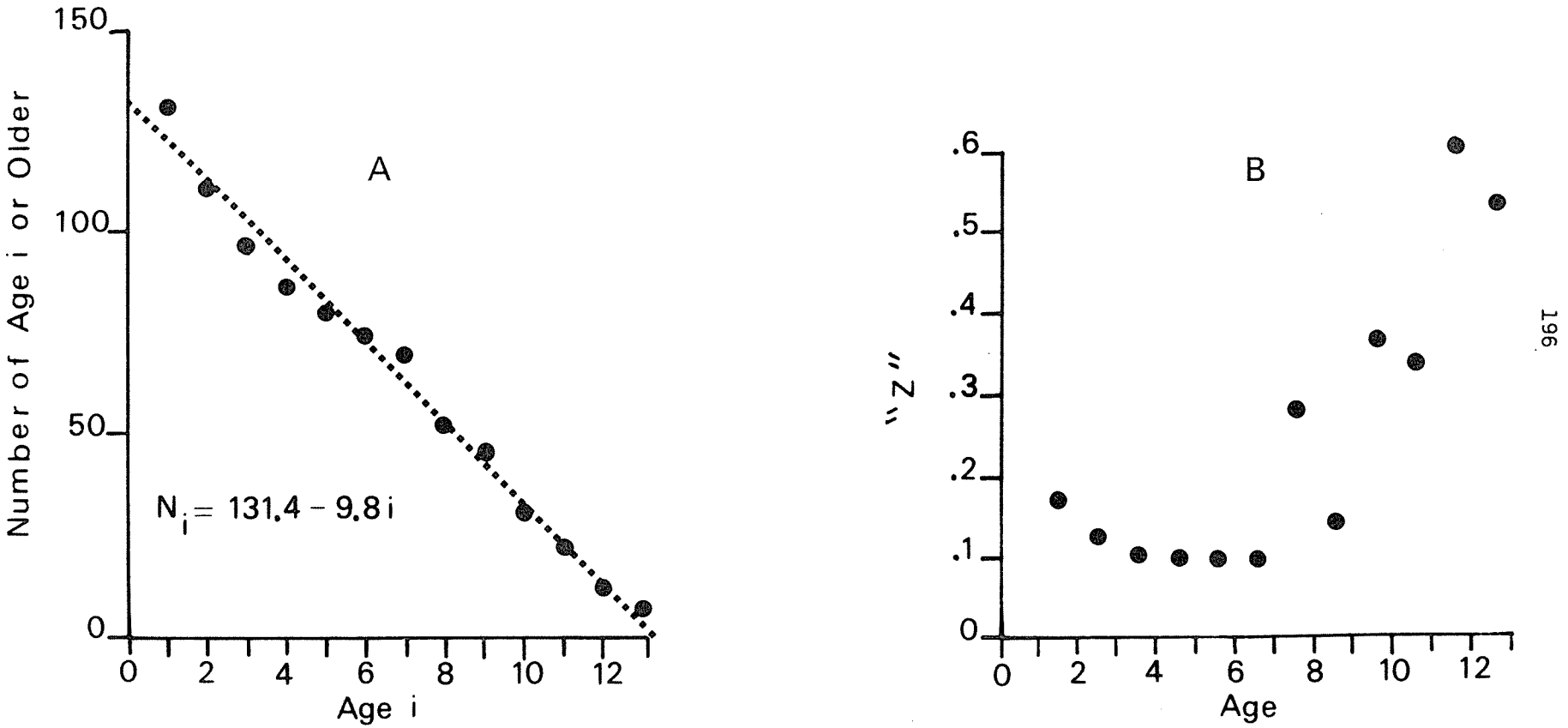


Fig. 7-35. A. Arithmetic cumulative survivorship curves for *S. giganteus* for all data.
B. Mortality coefficient (Z) of *S. giganteus* as a function of age.

Application of equations 6, 7, and 8 yielded the value of 7.2 g/0.25 m^2/yr for the area from -4 to -8 ft on all transects. The standing crop for this area, based on figures for transects 2, 4, 6, 7, and 8 at -4 and -6 ft was 68.5 ± 28.6 g/0.25 m^2 for a ratio of 9.5. The peak standing crop of this species (366.2 ± 152 g/0.25 m^2) was on transect 7 at -6 ft, as in the case of *P. staminea*. Thus, this area had a combined standing crop of *P. staminea* and *S. giganteus* of 826.6 ± 300 g/0.25 m^2.

The total standing crop for *S. giganteus* at Kiket Island in the area between the -4 and -6-ft contours is estimated at 270.5 kg and the annual production is estimated at 28.4 kg/yr. If the standing crop at -6 ft were taken as an estimate of the average value for the area between -6 and -8 ft (probably conservative for this species), the total for this area around the entire Island would be 991 kg. Thus, the total standing crop of *Saxidomus* is estimated at 1262 kg between the -4 and -8-ft contours.

Production and standing crop estimates for *Saxidomus* at various locations are summarized in Table 7-6.

7.4.8 Distribution and Growth of Other Important Pelecypods

In addition to the two species discussed above, several other pelecypods of lesser importance deserve mention by virtue of either their great numbers (*Macoma inquinata*) or their occasional use by man (*Clinocardium nuttalli, Mya arenaria, Tresus capax* and *Venerupis japonica*), or both (*Mytilus edulis*). A summary of data on the distribution, abundance, and growth of these species is given in Table 7-7 and Figs. 7-36 and 7-37. Additional details are available in the Appendix.

7.4.8.1 *Clinocardium nuttalli* (Cockle)

The cockle inhabited the relatively flat, muddy sand of the lower barnacle and *Zostera* zones from -5 or -6 ft down. It could be seen frequently either on the surface or partially buried in the sediments. Although the flesh is edible and easily obtained, it is not a popular food because of its toughness. The cockle was seen as high as -2 ft along transect 1 in an area where high run-off of water entrapped in the sand reduced desiccation. Peak abundance in sampling was at -6 ft, but even more probably occurred below this level. On

Table 7-6. Summary of calculations of production and standing crop of *S. giganteus* at various locations

Transect(s)	Level (ft)	S.C. ($g/.25m^2$)	n	Variance	Standard error	95% Confidence ($\pm g/25m^2$)	95% Confidence ($\pm$ per cent)	$\bar{P}$[1] ($g/.25m^2$-yr)	S.C.	Approximate area m	S.C. total kg	$\bar{P}$ total kg/yr
All (2,4,6,7,8)	-4 -6	68.5	114	23,187	14.3	28.6	42	7.2	9.5	15,800	270.5	28.4
(2,4,6,7,8)	-6	119.8	59	38,218	25.5	51.0	42					
2	-6	54.2	12	4,606	19.5	39.0	72					
4	-6	132.9	12	29,421	49.5	99.0	74					
4	-4	17.4	12	1,187	9.9	19.8	100					
6	-6	37.4	11	5,332	21.1	42.2	100					
7	-6	366.2	12	69,384	76.0	152.0	42					
7	-4	39.6	12	4,978	20.4	40.8	100					
8	-6	1.3	12	15	1.1	2.2	100					

[1] Based on all samples -4 to -8 ft less those from areas near solid rock.

Table 7-7. Summary of distribution characteristics of important pelecypods

	Clinocardium nuttalli (Cockle)	*Macoma inquinata* (Polluted macoma)	*Mya arenaria* (Eastern softshell)	*Mytilus edulis* (Bay mussel)	*Protothaca staminea* (Native littleneck)	*Saxidomus giganteus* (Butter clam)	*Tresus capax* (Horse clam)	*Venerupis japonica* (Japanese littleneck)
Highest level (on any transect)	-3 ft	+1 ft	+2 ft	+4 ft	+1 ft	-1 ft	-5 ft	-1 ft
Lowest level (on any transect)	-8 ft	-8 ft	-6 ft	-6 ft	-8 ft	-8 ft	-6 ft	-6 ft
Maximum number per sample (in any 0.25 m^2 sample)	4	190	15	981	60	7	4	1
Level of maximum number of (average over all transects)	-6 ft	-8 ft	0 ft	+2 ft	-8 ft	-6 ft	-6 ft	-1 ft
Transect of maximum number (average over all levels)	4	4	8	7	7	7	7	8
Preferred bottom type	Surface mud	(Silty sand and gravel)		solid rock	(silty sand and gravel)			

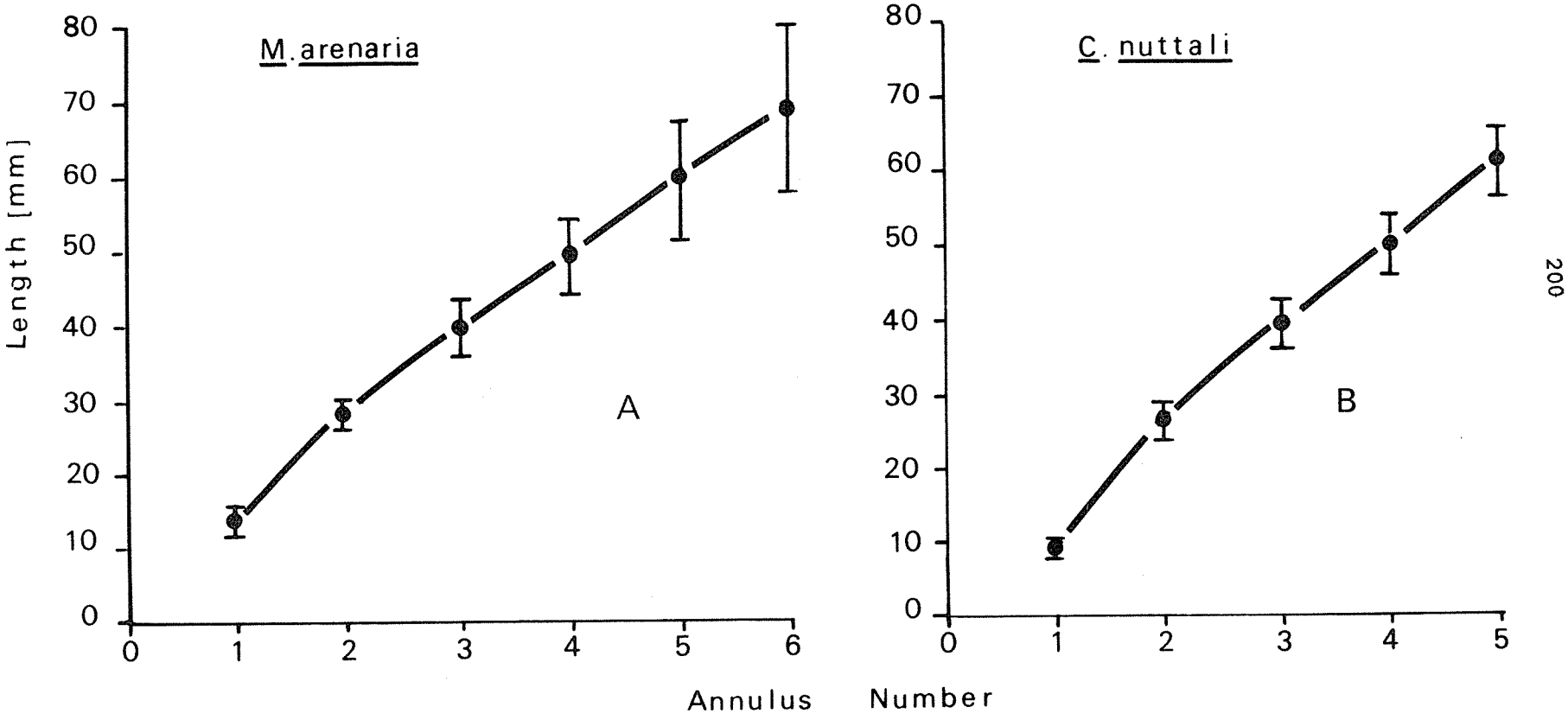


Fig. 7-36. Growth of *Mya arenaria* (A) and *Clinocardium nuttalli* (B) from measurements of annular rings for all data. Ninety-five per cent confidence interval of size at each age is given.

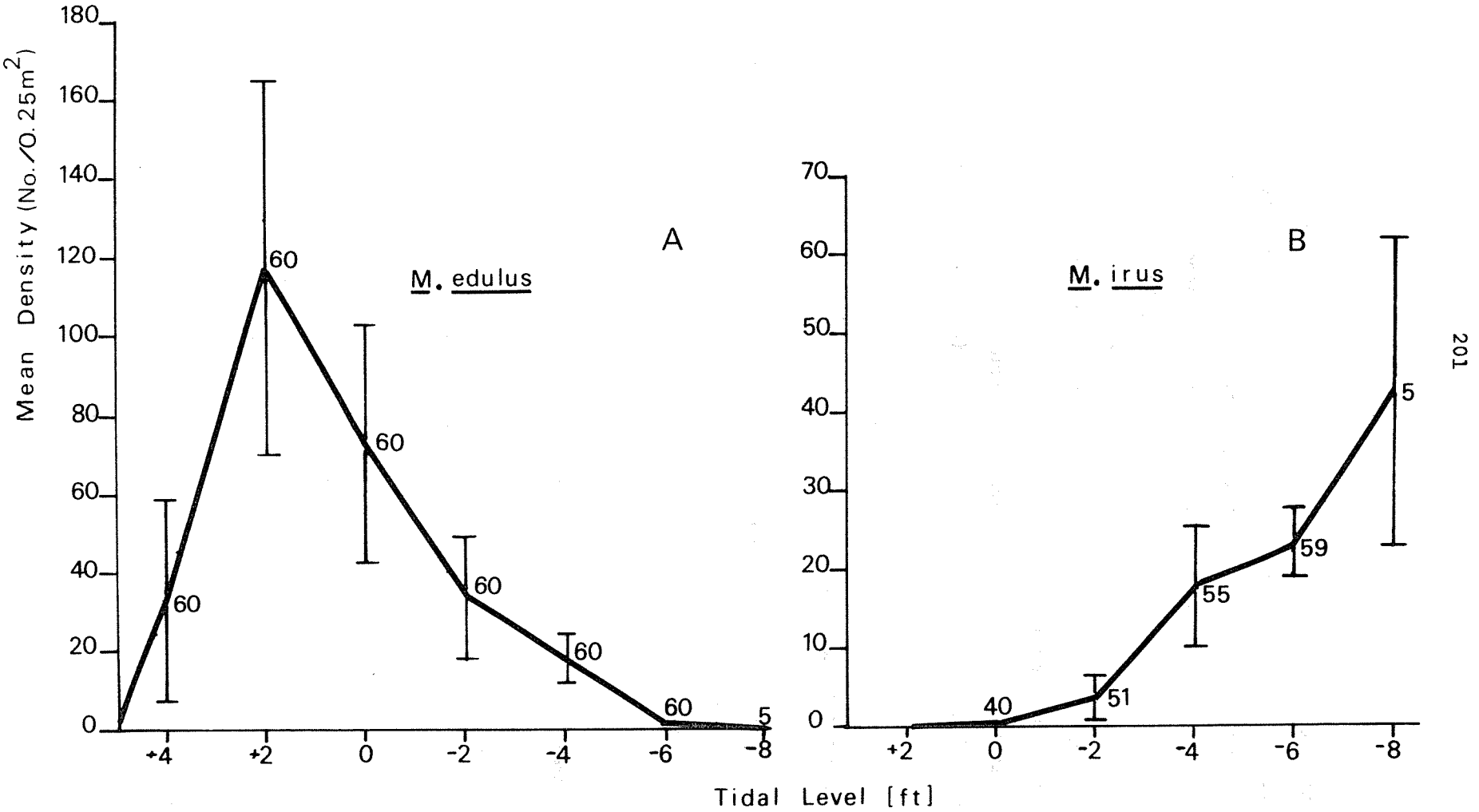


Fig. 7-37. A. Vertical distribution of *Mytilus edulis* averaged over transects 2, 4, 6, 7, and 8.
B. Vertical distribution of *Macoma inquinata* (=*M. urus*) averaged over transects 2, 4, 6, 7, and 8. (Numbers adjacent to data points are number of samples on which figures are based.)

the sandy *Zostera* flats at -6 ft on transect 4, average density was about 2.5/0.25 m^2, substantially higher than at any other transect.

C. nuttalli forms very distinct annular checks, usually including a sharp break in the contour of the shell. However, other distinct checks not associated with a break in shell outline were frequently formed in the first years of life. These were of uncertain origin and were sometimes called annuli and sometimes not, depending on their severity and proximity to a distinct annulus. Thus, the curve of growth for this species (Fig. 7-36B) may not be completely accurate, but the oldest individual found was probably not older than 5 years and growth was much greater than for the more widely used species.

7.4.8.2 *Mya arenaria* (Eastern Softshell Clam)

The softshell clam is probably an introduced species and has established itself at Kiket Island in limited areas not regularly utilized by native clams. Its highest occurrence in regular sampling as at +2 ft, higher than that of any other major subsurface bivalve. Peak abundance was at mean sea level on transect 8, where one sample yielded 15/0.25 m^2. The patchiness of the distribution of this species is demonstrated by the fact that the next highest number in any sample was only 4. It preferred quiet water and concentrated in silty areas behind protecting rock outcroppings. The largest beds were found at about mean sea level north and south of the causeway west of transect 1. Here, concentrations greater than 10/0.25 m^2 were found over large areas. Although it is more tender than native clams and is available on almost any low tide, this clam is not widely sought after in Puget Sound and no evidence was seen that anyone had dug for it on Kiket Island.

Age determination from annular rings is perhaps more difficult for *Mya* from Kiket Island than for those from broad stable mud flats, such as Skagit Flats, which are the typical habitat of the species. The coarser sediments at Kiket cause the organism to form much thicker shells with some confusing sculpture patterns. The growth curve in Fig. 7-36A is probably reasonably accurate, however, as older annuli were not included. The largest *Mya* taken at Kiket was 107.3 mm in length and estimated to be 8 or 9 years old.

7.4.8.3 *Tresus capax* (Horse Clam)

The horse clam was not taken in sampling on the south side of Kiket Island and was found only occasionally on the north side, at the -6-ft level. It is probable that the peak abundance of this species occurred below -6 ft, although none were taken at -8 ft. Where more than one individual was found in a sample (only at transect 7 -6 ft), most of them were immature and never more than one was an adult. *Tresus* was the largest clam at Kiket Island although the largest taken in systematic sampling (118 mm) was considerably less than the maximum size of dead shells seen on the beach. The formation of annular rings seemed to be relatively reliable for age determination except that the first ring was obscured by erosion in the umbonal region in older individuals.

7.4.8.4 *Venerupis japonica* (Japanese Littleneck)

This clam is an introduced species that has established itself in areas not occupied by native species. Its distribution was similar to that of *M. arenaria*, discussed above, and the two were frequently in close association. It is not common on Kiket Island, and only three were taken in all beach transect sampling. The largest numbers were found on the south side of the causeway west of transect 1 at about mean sea level. Age determination of this species from annular rings would appear to be equally as reliable as for *P. staminea*. Where the two occurred together, the Japanese littleneck showed a generally higher growth rate than the native species.

7.4.8.5 *Mytilus edulis* (Edible or Bay Mussel)

The mussel was the most abundant of the larger bivalved molluscs found. Densities reached many hundreds per 0.25 m^2 on rock outcroppings on both the north and south sides of the Island. On the north side peak abundance was found between mean sea level and +2 ft on the rock cliffs, whereas, on the cobble beaches of the south side, the peak was observed at -4 ft (Figs. 7-6 and 7-37A). A detailed evaluation of distribution and growth of this species at Kiket Island was presented in Section 5.2 of the 1971 Annual Report (Stober and Salo, 1971) and will not be repeated.

7.4.8.6 *Macoma inquinata* (Polluted Macoma)

This clam is seldom if ever eaten by man because of its small size and often unsavory habits. It is mentioned here only because of its major contribution to the biomass of infauna in many areas. *M. inquinata* was common on all transects below mean sea level and in all types of substrate, from clean cobble and sand on the south side of silty sand, gravel, and broken shell along the north side. It was often the most abundant clam in foul anerobic pockets of hydrogen sulfide-rich muck, from which it extends its long siphons for feeding and respiration. From Fig. 7-37B it appears that the over-all abundance of this species increased regularly with decreasing tidal level, although the number given for -8 ft may not be reliable because of the small number of samples involved. On the south side of the Island, when graphed independently, the peak abundance was clearly at the -4-ft level. The highest number for a sample (190/0.25 m^2) was found at that level at transect 4. On the north side very few were present until the -6-ft level, where abundance increased sharply (66/0.25 m^2 in one sample at transect 7). Analysis of variance did not show any significant difference between transects. Distinct checks were evident in the external sculpture of the specimens of this species, but no attempt was made to use them in age determination.

7.4.8.7 *Crossostrea gigas* (Pacific Oyster)

The Pacific oyster was not abundant at Kiket Island, occurring only once in systematic sampling (-4 ft on transect 2). Several large specimens were seen on the bench near transect 5 and on the low mud flats north of the causeway. In addition, a few individuals were seen at various locations on the rock cliffs on the north side and among the cobble on the south beaches. The large size of all individuals indicates that natural recruitment is very infrequent despite the presence of a commercial oyster farm in the upper end of Similk Bay. It is possible that a slight increase in the summer water temperature regime might stimulate natural reproduction of this species.

7.5 DISCUSSION

7.5.1 General Composition of the Biota

7.5.1.1 Taxonomy

The taxonomic problems involved in an ecological survey of a marine benthic community cannot be fully appreciated by one who has never undertaken such a task. When it is desired to compile a "complete" species list for the area in question, so that future additions to or deletions from the biota may be recorded, the difficulties multiply. Of the remarkably few published accounts dealing with intertidal ecology within Puget Sound, fewer still have attempted a comprehensive inventory of invertebrates at any given location. This is not surprising in view of the fact that one of the most widely distributed species of amphipodat Kiket Island was returned from the country's foremost amphipod specialist as "Eusirid-genus undescribed." It was accompanied by a suggestion that I describe it, if I were so inclined! Such is the unfortunate state of the taxonomy of numerous major groups of invertebrates (and algae) in Puget Sound. This may well constitute a considerable portion of both the cause and effect of the paucity of study in this region.

There are strong arguments both for and against the expenditure of the scientific effort required to establish a relatively complete inventory of species in an area. Perhaps the strongest reason favoring such effort is the obligation to provide future workers with the best possible historic record of the biota, in this case of Puget Sound, in as virgin a state as possible. Only with this information can the full impact of man's influence on natural processes be assessed.

The species list established during this study (Appendix 7.A) represents a considerable proportion of the total effort devoted to the analysis of the various phases of the work. Yet it is by no means complete either in terms of the number of species collected or in terms of the identifications of those which were collected.

For the area above mean lower low water (-6 ft) the sampling was intense for macro-organisms of the epifauna, infauna and algae, and probably in the vicinity of 95 per cent of species from this area were recorded. Relatively few (6) quadrat samples were taken in soft bottom areas below -6 ft. Only 6 species of invertebrates not sampled at higher levels were added, and, of these,

three were nemerteans. However, because of the high diversity at these lower levels and the low density within species, further sampling could be expected to continue to add new species at this same average rate (about 1 per quadrat) for some time. The epifauna of the rocky benches and cliffs below mean lower low water were not sampled systematically, and thus no estimates were made of diversity or rate of addition of new species. Repeated collecting trips to two areas of this substrate (Flagstaff Point and just north of the laboratory Fig. 7-1) continued to produce new types although at a diminishing rate. Perhaps 90 per cent of macroinvertebrates from the area below -6 ft were collected along with a slightly lesser percentage of the algae.

Of the organisms collected or noted in the field several taxa were particularly troublesome to identify. In addition, the anenones were extremely difficult to collect and preserve, and no attempt was made to identify several small nondescript types which are probably not described. Bryozoans were not abundant and were not separated, although four or five species were taken. The systematics of local Nemertinea have not been well worked out, and at least one form which was fairly common at Kiket Island is from an undescribed genus. Time did not permit identification of others because of the detailed histological preparations required. Problems were also encountered with some species of most of the other groups of organisms either because of inadequate keys or inadequate specimens. In most cases limited time did not permit reference to original descriptions.

7.5.1.2 Comparative Richness

Despite these qualifications the species lists obtained from Kiket Island (Appendix 7.A) appear more complete than any published to date for a single area in Puget Sound and longer than those from any other northwestern intertidal studies. Several factors contributed to this apparent richness of Kiket Island intertidal fauna relative to other intensively studied areas. First, the intertidal of Kiket Island is comprised of three completely different substrata (rock, sand, mixed sediments), all of which were sampled intensely; whereas the majority of other intertidal studies have concentrated (perhaps wisely) on a single substrate, usually rock. The inclusion of infauna from the cobble and sand beaches added a large body of species which are frequently overlooked. Of the 84 species of polychaetes taken, at least six, all

from the infauna, were new to the Washington-British Columbia area. Nybakken (1969) is the only other recent worker to study several intertidal habitats in one area including sieving of sediments from mixed cobble beaches as well as reefs, cliffs, and tide pools. In one summer of sampling on Kodiak Island he took only 57 species of invertebrates using techniques similar to mine but with a minimum mesh size of 3 mm versus the 1 mm used for cores in this study. This minor variance certainly accounts for only a very few species. All but 11 of these 57 species were also taken intertidally at Kiket Island with at least 4 more common subtidally. The major differences between the two studies in terms of reported species richness are in the greater severity of the environment at Kodiak Island and the greater silt content in the cobble and mixed beaches (e.g., transect 7) at Kiket Island.

Shelford et al. (1935) in their "provisional map of the communities of the sea bottom about San Juan Islands" placed the upper beaches and all rocky portions of the Kiket intertidal in the "*Balanus - M. edulis* faciation" of the "*Balanus - Littorina* biome." The soft bottom areas below about mean sea level were put in the "*Macoma - Paphia* (*Protothaca*)" association of the "*Macoma - Paphia* biome." The generalization involved in mapping communities in this way are unavoidable but tend to obscure local ecological factors which are important in determining the distribution and abundance of species in a given area. The species lists of "dominants" and "influents" in the biomes supposedly found at Kiket Island contain several species not found there and omit many others of importance.

Although no comparable studies are available for other parts of Puget Sound, it is my impression that the fauna in the main body of the Sound is generally more diverse than that at Kiket Island. Certainly there are many species of obvious epifauna in the Sound which were absent or extremely rare at Kiket Island (e.g., *Anthopleura, Nassarius, Petrolisthes,* serpulids). Several bivalves which are abundant throughout much of the Sound were also scarce or absent at Kiket Island (e.g., *Macoma secta, Venerupis* 2 spp., *Lucina* 2 spp.). The species which were rare at Kiket Island but abundant in the Sound were invariably found on the less rigorous Similk Bay side of the Island and were completely absent on the south side. The probable causes of these absences are the high silt load and low salinity from Skagit River run-off. The inorganic silt would especially effect filterfeeders by clogging

filtering structures with inedible material. The occasional low salinities at Kiket Island would eliminate less euryhaline species of all taxa.

The "niches" made available by the intolerance of these species would in most cases be filled by expansion of the niches of species also present in the Sound rather than by species not found in the Sound.

7.5.2 Patterns of Distribution

7.5.2.1 Local Variations in Species Richness

Sampling at several locations about Kiket Island revealed several patterns of variation in species richness, some of which were not obvious prior to the start of studies. Environmental factors primarily responsible for these patterns include tidal level, type of substrate, exposure (to the sun), salinity, silting, and biological factors such as predation and competition.

Substrate was especially important as a modifier of the effect of tidal level on species richness. At upper tidal levels (above mean sea level) there were significantly more species in areas of solid rock than in cobble or sand, especially on the south side. At midtide levels where infauna was more diverse there were about the same numbers of species on all substrata. At lower levels the species richness of epifauna on the beaches was still less than that on rock, but the large number of infaunal species added to the epifauna made the total species richness much greater than on the rock.

It is difficult to evaluate which of several possible factors were responsible for the much greater species richness and diversity at any tidal level on the north side than on the south side (Figs. 7-2 and 7-3). Probably most important of these was the northern exposure itself and the high cliffs and trees which effectively shield much of the area from midday sun during the summer daytime low tides. On the vertical transects exposure to the sun was seen to definitely depress the tidal level at which a given zone occurs, but it could not be shown that the species richness within a zone was affected. The exposure to increased desiccation, coupled with greater extremes of temperature and salinity on the south side no doubt played a part in reducing the species richness.

Some factor associated with the Skagit River discharge is certainly implicated by the results of samples taken from +4 to -4 ft on the south

side of Hope Island. This sampling was done in the summer of 1970 on a beach which appeared to be nearly identical to that of transect 2 in terms of slope, composition, and exposure to the sun. Although only slightly more than a mile south of Kiket Island, this area is exposed to a low saline layer from the Skagit effluent. This water is subsequently mixed to some degree, in passing around Hope Island, before it contacts the south shore at Kiket Island. The fauna of the south side beach at Hope Island was severely impoverished relative to that of even transects 2 and 3 on Kiket Island, probably a result of the extremes in salinity. Infauna was especially reduced on Hope Island, consisting mostly of oligochaetes, centipedes, nemerteans, and a few *Nereis vexillosa* at the -4-ft level with no bivalves at all. It thus resembled the infauna of the upper barnacle zone on Kiket Island which occurred between 0 and +3 ft!

In addition to a higher and more stable salinity, the greater diversity and abundance of deposit feeders on the north side of Kiket Island may be dependent on the somewhat lesser magnitude of currents and wave action in Similk Bay permitting deposition of a much greater amount of silt within the cobble and gravel sediments.

Finally, at a given location selective predation on the dominant organism may allow the development of a more diverse community than would occur in the absence of predators when the dominant often tends toward a monoculture (e.g., Paine, 1966). This may be responsible in part at least for the lower species richness on the rock bench of transect 5 where no *Leptasterias* were found and large *Mytilus* were dominant, as opposed to transect 6 where increased shading allowed survival of *Leptasterias*. The *Leptasterias* cropped the *Mytilus* and permitted development of a more diverse epifauna. Other factors may also have contributed to this contrast, although the areas were very close physically.

7.5.2.2 Zonation

The descriptions of zonation at Kiket Island are offered merely as a means of representing the changing character of the intertidal community across the range of tidal levels and as a means of relating conditions at Kiket Island to those elsewhere. It is recognized that the boundaries between these zones are, to varying degrees, indistinct and subjectively defined and

that there are numerous deviations in their levels due to local microenvironmental conditions. Since description of zones was not an end in itself, an effort was made to avoid introduction of a new terminology. For the most part, the "universal scheme" of Stephenson and Stephenson (1949) was followed, including their optional breakdown of the midlittoral (balanoid) zone into three subzones (Fig. 7-38). The *Zostera* zone is added to account for the soft bottom "infralittoral fringe" as was done by Nybakken (1969).

7.5.2.3 Overall Clarity of Zonation Patterns

7.5.2.3.1 Physical Factors. Zonation patterns at Kiket Island were not as distinct as they appear to be in the main body of Puget Sound and did not approach the clarity which is typical of areas of exposed outer coasts. In their comparison of the "*Balanus-Mytilus californianus* association" of the open coast with the "*Balanus-Mytilus edulis* association" of the protected side of the same island, Shelford et al. (1935) noted a much less definite arrangement of species into distinct "faciations" (zones) on rock surfaces in the latter environment than in the former. The variables they mentioned as possible causative agents were the lesser wave action and greater freshwater influence on the protected shore. Stephenson and Stephenson were credited by Doty (1957) with recognizing that the intensity of zonation was greater in places with a higher degree of wave action. It was reasoned that the physiography responsible for dissipating the waves might also introduce factors such as "shading and wind" which would complicate the patterns of zonation, even though the tides were the same as on an exposed coast. The number of potentially confusing physical factors at Kiket Island and in Puget Sound is large, including variables such as wind, waves, insolation, large freshwater input from rivers and heavy rains, extreme temperatures during low tide periods, silt loading, and highly complex local tide patterns. A wide range of hypotheses can be developed using various combinations of these factors.

One of the more appealing of these invokes Doty's critical tide factor theory (1946), which holds that zonation in areas of semi-diurnal mixed tides is in large measure controlled by sudden two- and three-fold increases in the maximum period of immersion or emersion which occur within a few inches of vertical distance. These factors include the lowest lower high water, LLHW (highest level covered and uncovered at least twice each day), lowest higher

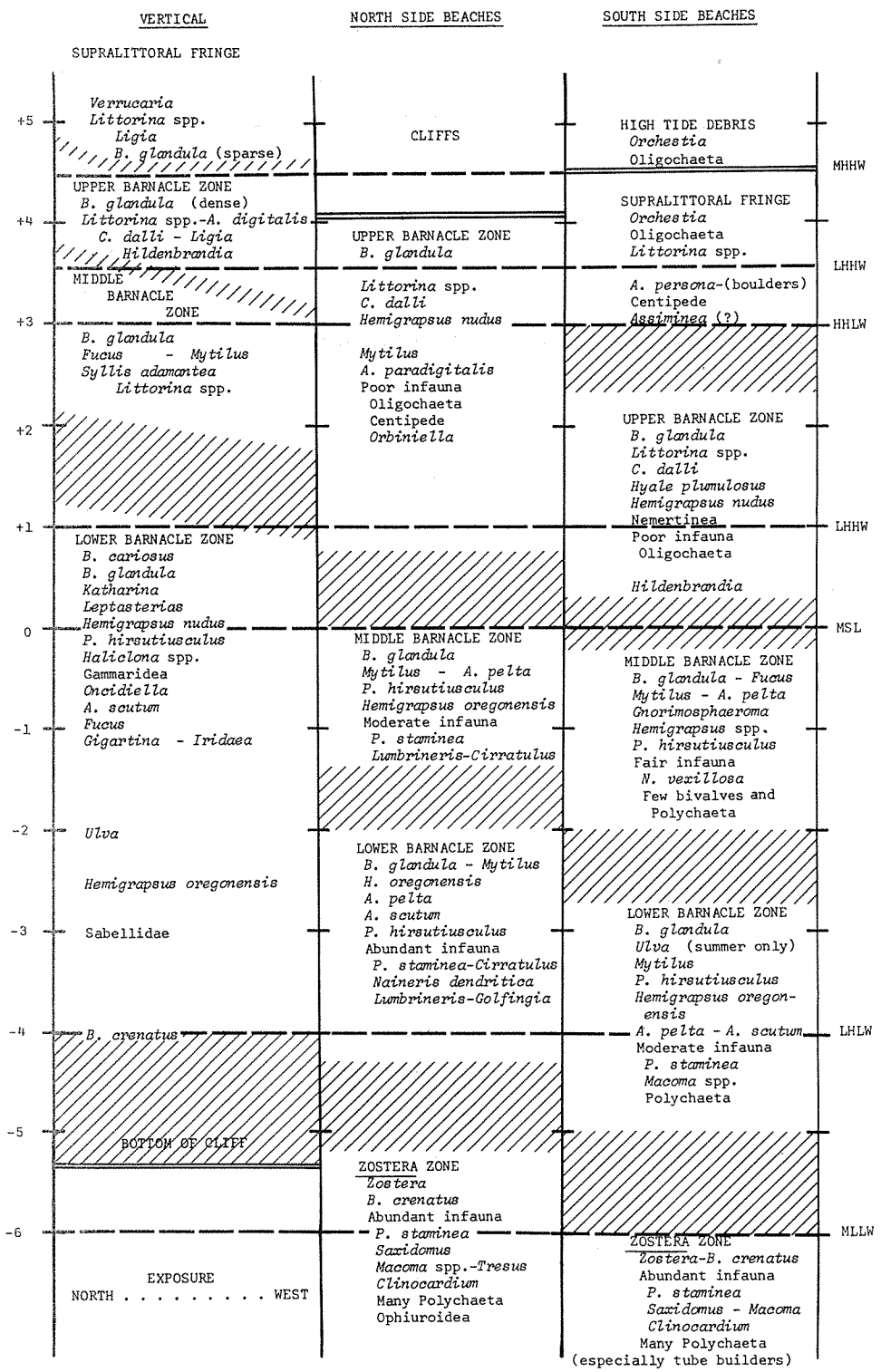


Fig. 7-38. Comparative zonation at Kiket Island including species typical of each zone. Cross-hatching indicates areas of transition.

high water, LHHW (highest level covered at least once each day), lowest higher low water, LHLW (highest level uncovered only once each day), etc. Several of the zonal transitions at Kiket Island correspond well to these levels (Fig. 7-38), but in looking at tide charts for more than one year, it is discovered that the level at which these extremes occur during the critical summer months varies from year to year by at least 0.5 ft. Within the narrow confines of Skagit Bay the frequently strong winds often alter the high or low tide by a foot or more from the predicted levels. Thus, the critical tide levels could easily vary by 1.5 ft or more from year to year, greatly confusing zonation patterns, depending on the relative tolerances of the organisms subjected to the increased duration of immersion or emersion. The effect of prolonged emersion may also be modified by relatively strong wave action, high humidity, or overcast, all of which are frequent in the Puget Sound region. It is not known whether annual fluctuations in the level of these critical tide factors are this great in other areas displaying intense zonation.

7.5.2.3.2. Biological Factors. It is surprising that until fairly recently biologists have largely overlooked the importance of certain biological interactions that greatly influence zonation patterns. For example, Stephenson and Stephenson (1961*a*) marveled at the appearance of relatively bare rock with only a large population of various starfish in the lower intertidal near Nanaimo, B.C. Recent work by Paine (1966) demonstrated that a strong cause-effect relationship exists between the predatory starfish and gastropods and absence of attached macrofauna. Studies by Connell (1961*a* and *b*; 1970), Dayton (1971) others support the idea that competition and predation (including herbivory) play a critical role in dictating the distribution of intertidal organisms. They have shown that intertidal organisms such as mussels and barnacles are well-adapted to survive at much lower tidal levels than they are found naturally. The lower limits of these organisms are, in many cases, established by the upper physiological limits of a key predator or competitor rather than by their own lower physiological or reproductive limitations.

A reasonable explanation for the increased intensity of zonation on exposed coasts may be the increased severity of predation and competition. Perhaps the more ideal conditions (stable salinity and temperature, predictable tides, constant wetting by waves, etc.) of the outer coasts allow survival

of a more diverse array of organisms, particularly gastropod and echinoderm predators, that increases the biological stresses and leads to the typical, distinct zonation patterns. In protected and estuarine waters such as Puget Sound the rigors of the physical environment (variable salinity and temperature, unpredictable tidal patterns, high degree of silting and desiccation) limit the variety of organisms present and restrict others to lower tidal levels than they would otherwise occupy.

Because of their proven influence on intertidal zonation and their sensitivity to desiccation, the predaceous starfish are an excellent group to consider in this light. On the outer coast *Mytilus californianus* is prevented by starfish from establishing a monoculture throughout much of the intertidal range (Paine, 1966). The lower margin of the mussel zone is an extremely sharp line formed at the upper limit of starfish predation at 1 to 2 ft above MSL (Paine, 1973, personal communication). At Kiket Island the same species of starfish (*Pisaster ochraceus*) is not abundant and is restricted to the area below mean lower low water (-6 ft) except in a few crevices. Its range of predation is limited to below -4 ft and is further reduced by the geography of the Island. Where the rock cliffs intersect the beach above -6 ft there are no refuges below this level for the *Pisaster* to wait out low tide periods, as they have an apparent dislike for soft bottom. Thus, they are very seldom seen in such areas, although ample food is available at relatively low tidal levels. *Balanus glandula, B. cariosus* and to a lesser extent *Mytilus* are abundant at Kiket Island well below the range they normally occupy in the rigorous biological environment of the outer coast. Other notable absences of species will be discussed with the comparisons of the distribution patterns at various locations about Kiket Island.

In contrast to the results of Nybakken (1969), the zonation patterns on the beaches at Kiket Island were far less distinct than those on the cliffs. Transition from zone to zone seemed to involve a foot or more in elevation and hence, several feet of beach. The sloping beaches offered little protection to starfish predators which were absent above -6 ft except on a few large boulders. Although *Thais* was present in numbers as high as -4 ft their predation was probably limited to barnacles on the moist lower margins of the cobble and had no detectable effect on the dense *B. glandula* coverage on the upper surfaces.

Sampling techniques which did not include a continuous range of tidal levels may have contributed to the lack of definition, but if the zones were sharply distinct, it would be expected that there would have been greater discontinuities in the distributions of species between the levels sampled than was shown. It may well be questioned whether or not sufficient evidence exists to describe zones at all, on the beaches. In answer, it seems certain that the supralittoral fringe, the barnacle zone (midlittoral) and the *Zostera* zones are distinguishable and sufficiently homogeneous over a considerable extent of tidal range to be considered as separate communities, even though the transitions from one to another are relatively broad.

The breakdown of the barnacle zone into subzones has been frequently done, usually on the basis of the presence of a fairly sharp band of *Fucus* which was not present at Kiket. The absence of this distinct *Fucus* zone on the cobble beaches is difficult to explain in view of its abundance on vertical and sloping rock outcroppings all around the Island. The cobble in most of the areas is highly stable, so instability of the substrata should not be responsible. What *Fucus* there was on the south side beaches began at about mean sea level, coincident with the presence of significant infauna and thus served as a secondary indication of the start of the middle barnacle zone. On the north side however, *Fucus* was sparsely present on cobble as high as +4 ft and was of no use in delimiting zones.

Breakdown of the barnacle zone into three subzones on the basis of the character and abundance of infauna was perhaps overly subjective because of the discontinuous sampling effort. The justification for this was taken from the radical changes which were seen in the infauna under the broad band of beach where the epifauna was dominated by *Balanus glandula*. At upper levels infauna was virtually absent; in middle levels it was sparse and dominated by polychaetes; and in lower levels it was rich in polychaetes, pelecypods, and other organisms. The conditions described were real, but whether the indications of the presence of distinct zones was introduced by the distribution of sampling effort (at 1 or 2 ft intervals of tide height) or by real breaks in the distributions of organisms is not certain.

7.5.2.4 Relative Clarity at Various Levels

At upper tidal levels it would be expected that zonation would be more dependent on physical than on biological stress factors and perhaps distinct in all environments. Zonal boundaries on the rocky cliffs at Kiket Island were in fact reasonably obvious and clearcut at upper tidal levels, occurring over a few inches of vertical height at any one location but varying in level depending on insolation. Below the upper boundary of the middle barnacle zone (-3.5 ft) they were much less distinct.

At lower tidal levels where physical stresses are less severe, it might be expected that the intensity of zonation patterns would be more dependent on the rigor of the biological environment. The shift from the middle to the lower barnacle zone on the cliffs involved a vertical range of a foot or more where *B. cariosus* gradually took over dominance of the primary space from *B. glandula*, first in more protected crevices, then on exposed outcroppings. From a distance it was not possible to detect this change and only a gradual increase in *Ulva* cover marked the transition. On the few low rocky areas where a shift to the *Laminaria* zone was possible there were also no sharp breaks. A thinning of the dense barnacle growths took place as predation intensified, and there was a gradual infusion of new species typical of the lower zone.

Several workers have noted this diminishing clarity of definition of zones at lower tidal levels (Beveridge and Chapman, 1950; Rigg and Miller, 1949; Nybakken, 1969). Others have found just the opposite, however, and Doty (1957) related the increasing sharpness of breaks between zones in mid and lower regions to the increasing rate of change of tidal level. Apparently the variability in extent of transitional areas between zones depends on local hydrographic and biological conditions which in most studies are not defined.

7.5.2.5 Comparison of zonation on cliffs and beaches

Quadrat sampling on the beaches and cliffs at Kiket Island revealed some interesting contrasts in terms of the abundance and distribution of certain organisms and hence the resulting zonation patterns. The most striking of these was the tidal level at which the zones appeared on the three areas

shown in Fig. 7-38. On the north facing cliffs the upper boundary of *Fucus* growth was at about +3.5 ft, the level of lowest higher high water, i.e., the highest level which is covered by tides at least once a day. The actual level was depressed 0.5 to 1 ft on west facing cliffs and 1 to 1.5 ft on south facing rock by increased desiccation. Wave action and the normally higher level of most higher high waters were sufficient to extend the upper limit of dense barnacle growth to about +4.5 ft on the north cliffs. This upper boundary of the upper barnacle zone was somewhat less influenced by moderate insolation and stayed at about the same level from northern to western exposure on the vertical transects, but occasionally reached +5 ft in north facing crevices. In contrast, on the south side rocks, dense barnacle growth was not encountered until the +3-ft level, and on the south beaches not until the +2-ft level. The limited northern beach area at the +4-ft level in a deep cove at transect 8 had some *B. glandula*, but they were not highly abundant until the +2-ft level. Differential wetting by waves was largely responsible for the higher level of dense barnacle growth on rocks than on beaches. For example, a wave of a given amplitude may wet a near vertical rock surface upwards for a foot while dissipating on a beach without wetting more than a few inches vertically.

Balanus cariosus was very abundant on the cliffs on the north side, and its dominance of the primary space throughout the lower barnacle zone was considered a distinguishing characteristic of that zone. On rocky areas on the south side this species was very rare with only a few at -3 ft on the rocky bench of transect 5. On the south side cobble beaches it was virtually absent; while on the north cobble beaches it was present, but not abundant, on larger cobble from +2 ft to -6 ft, about the same range as on the northern cliffs. This distribution must be the result of sensitivity to insolation, since Rice (1930) and Worley (1930) found this species to be relatively more abundant in areas of low salinity such as might be expected on the south side. This is another example of how the rigorous physical environment has eliminated competing species and allowed the extension of remaining species (e.g., *B. glandula*) resulting in muted zonation patterns.

The higher level of the upper barnacle zone on the north beaches than on the south is certainly due to shading, but it is interesting that the lower zones occur at more nearly the same levels. This is no doubt because these

zones were based on infauna which are less affected by insolation. However, in addition to the north side being always richer in species at a given level than the south, most species also had a higher upper limit on the north resulting in the somewhat higher extension of each zone (Fig. 7-38). Probably this effect would be even more marked at lower levels were it not for the dense mat of *Ulva* which covers and protects the lower beaches on the south side during the hottest summer months (Fig. 7-17).

7.5.2.6 Comparison with Other Northeast Pacific Studies

The zonation patterns found at Kiket Island are in reasonably good agreement with those described for other protected locations in the Pacific Northwest. The studies of the Sephensons (1961*a*) at Brandon Island near Nanaimo, B.C., dealt with an area with topographic similarities to Kiket Island, such as sloping beaches with southern exposure and near vertical northern cliffs. The zonation they found has many parallels with that encountered at Kiket Island and, not surprisingly, fits well into their "universal scheme" of intertidal zonation (Stephenson and Stephenson, 1949). On the north cliffs at Brandon Island there was a very narrow band of dense *B. glandula* (upper barnacle zone) above the *Fucus*. The *Fucus* zone was also narrower than at Kiket Island extending only a few feet from its upper boundary (no exact levels are given). Barnacles and mussels were very sparse fairly high up in this midlittoral zone, certainly the result of *Pisaster* predation, although this can only be inferred from their discussion of the depauperate fauna. *Pisaster* was abundant in the rocks of the infralittoral fringe, and their absence at Kiket Island has been assumed to be at least partially responsible for the vertical extension of the lower barnacle zone from +1 to -4 ft. As was the case at Kiket Island, the zonation on the south side beaches of Brandon Island differed from that on the north side cliffs in having the upper limit of barnacles and *Fucus* a foot or more lower, and in having dense growths of barnacles continuing to somewhat lower levels. The former effects are certainly the result of desiccation on the south side, and the latter effect is probably caused by the inability of starfish predators to forage up the sloping beach without being stranded by receding tides. Unlike Kiket Island, however, Brandon Island had sharply defined zonation on

the south side beaches, including a band of *Chthamalus dalli* at the top of the barnacle zone and a well-defined band of dense *Fucus* growth indicating that the physical environment was somewhat less rigorous than that at Kiket Island.

Studies by Nybakken (1969) on the intertidal ecology and zonation at Three Saints Bay on Kodiak Island, Alaska also included both vertical cliffs and sloping cobble beaches. Because of the maritime climate of that region including frequent overcast and dense fogs, especially in July and August, the effect of insolation was probably much less severe than at Kiket Island where the lowest daytime tides were often coincident with the brightest sunshine of the year. None the less, Nybakken noted the same pattern of lowering of the upper limits of barnacles and *Fucus* on the beaches 2-3 ft below their levels on the vertical transects. His zonation scheme showed no equivalent to the supralittoral fringe or "splash" zone of other workers. He found no appreciable organisms higher than the upper limit of barnacles except on his vertical transects and he did not consider including this upper area as a distinct zone. His "barnacle zone" is the equivalent of the "upper barnacle zone" at Kiket Island, and his "*Fucus* zone" includes both the "middle" and "lower barnacle zone" at Kiket Island. Barnacles were abundant through the *Fucus* zone at Kodiak, but because of the very visible *Fucus* cover (lacking on the beaches at Kiket Island) his terminology was appropriate. On the vertical transects at Kodiak Island, he reported a distribution of barnacles similar to that shown for Kiket Island in Fig. 7-10. The same transition of dominance from *B. glandula* to *B. cariosus* occurred at about 2 ft above MSL, but at Kodiak there was no break in the fauna above and below this transition area as was the case at Kiket Island. Thus, Nybakken's *Fucus* zone extended from about +2.5 ft to -2.3 ft where the *Odonthalia-Laminaria* zone began and continued subtidally. This is unusually high for the start of this lowest zone which typically starts near mean lower low water, about -4.3 ft (relative to MSL) at Kodiak. At Kiket Island there was a significant drop in *Fucus* cover below the -3-ft level, but the limited extent of the cliffs in the study area obscured the character and sequence of lower patterns.

One of the sharper contrasts between the distribution of conspecifics at Kodiak and at Kiket Island was the presence of *B. cariosus* through the entire range of the barnacle and *Fucus* zones on the cobble beaches at Kodiak.

B. glandula was present in small numbers only in the upper portion of the eelgrass zone, whereas on the beaches at Kiket Island it dominated the entire range of barnacle zones in the almost complete absence of *B. cariosus*.

The eelgrass zone reported by Nybakken at Kodiak Island is a direct counterpart of the *Zostera* zone at Kiket Island. However, of only 16 species of invertebrates reported from this zone at Kodiak, one-half were present also throughout the *Fucus*, leaving only 8 species which were "typical" of this lowest zone. This contrasts sharply with the overwhelming richness and diversity of this zone at Kiket Island (e.g., 98 species of animals at transect 7 - 6 ft alone).

7.5.3 Distribution, Age, Growth, and Production of Major Bivalves

7.5.3.1 Distribution

The distribution of higher densities of bivalves with sport or commercial importance was in most cases well-correlated with areas of greater richness and abundance of other organisms. With *Protothaca staminea*, for example, trends were established for higher densities at lower tidal levels, on the north side of the island, and in mixed sediments with high silt content. These trends were subject to modification by localized conditions such as underlying rock or impermeable hardpan that increased water retention. This correlation confirms that the same factors discussed above as controlling distribution of the majority of invertebrates, act also on these clams.

The preference of deposit feeding animals for a substrate with a high loading of silt and organic detritus is obvious. These organisms constitute early stages in the food chain supporting a diverse infaunal community. In the case of filterfeeding invertebrates, the cause of aggregation in such sediments is less evident as they do not derive any nourishment directly from them. The most probable cause for this association lies in the increased water retention of sediments with a higher percentage of fines. In addition, the absence of fines often indicates that sediments are unstable or recently shifted. This was the case from -3 to -5 ft on transect 8 where numbers of clams and other organisms were very low in the wake of a berm of clean shell and gravel which was moving up the beach. The tendency for *P. staminea* to thrive in mixed sediments and those with considerable silt included was noted

also by Fraser and Smith (1928*b*). In addition, they found a dearth of this species in areas of clean sand as was the case at the -6-ft level on transects 2, 3, and 4 at Kiket Island. *Saxidomus* and *Clinocardium*, being moderately abundant in the sand at -6 ft on transect 4 provided some exceptions to the distributional trends of *P. staminea*.

7.5.3.2 Ageing

In ageing organisms by means of growth rings on some hard structure of the body, confusion frequently exists over interpretation of the first check laid down. Since the exact time of setting (or hatching) is usually not known it is convenient to consider the size at the time of formation of the i^{th} check as "size at age i." If the first ring is not counted, then the length at "Yr 1" really includes the growth of the first full year, plus whatever growth was put on after setting in the first year. If the first ring is counted, then growth from setting, usually in the spring or summer, to the first winter is considered as a full year's growth. Although this would seem to introduce error as well, it is compensated for in the calculation of t_o in the von Bertalanffy growth equation (equation 1). In *P. staminea* and *S. giganteus* growth in the first year (even though it is not a full year) was very nearly equal to that in the second year, (Fig. 7-26) but this effect may have been added to by the arbitrary omission of very small (<3 mm) first checks. Because of the substantial growth made in the first year in all species the first check was considered the length at age 1 within the restrictions discussed in "Materials and Methods" above. It is essential that this point be brought out in each study of this type.

The series of monthly samples of *P. staminea* taken during 1972, and the marking experiments performed concurrently, provided a high degree of confidence in the ageing of this species and in the technique in general. Unfortunately, they were not concluded until after all measurements had been made on the clams on which the analysis of age and growth were based. These *post facto* studies did confirm that procedures used and judgments made in ageing these clams were, by and large, correct. However, it is probable that the accuracy of ageing could have been improved somewhat in the earlier measurements by the knowledge gained in these experiments, particularly with regard to distinction between severe disturbance checks and true annuli. (Marking

experiments attempted during the summer of 1971, in the outdoor troughs at the Kiket Island laboratory, failed because of a water outage.) Future marking experiments should be continued through at least one entire year to guarantee that only one ring is formed during the period from late fall to early spring.

7.5.3.3 Age Structure

Several interesting conclusions can be drawn from inspection of age frequency distributions for *P. staminea* taken in all beach sampling (Fig. 7-29B) and at three levels on transect 7 (Fig. 7-30). It is obvious from all of these distributions that the success of recruitment is not constant from year to year. Strong year classes can be seen as corresponding peaks on the histograms from the two years of sampling. On an island-wide basis, (Fig. 7-29B), the strongest year classes were 1963, 1964, and 1967; however, the year class strength varied surprisingly on the three different levels of transect 7. The 1967 year class, which was very strong at -4 ft, was very poor at -6 ft and mediocre at -2 ft. In contrast, the 1969 year class was very strong at -6 ft and below average at -4 ft. This implies that recruitment is patchy with respect to space as well as time. Presumably the tidal level of peak setting must vary from year to year with the variable height of the tide and prevailing current patterns at the time the larvae settle from the plankton.

The presence of large numbers of several older age classes indicates that clam stocks were largely unexploited in the areas sampled. In fact, moderately heavy digging was observed from time to time in the vicinity of transects 6 and 7, but the usual preferred species of the Indian diggers was *Saxidomus* and their effort was generally concentrated below -6 ft. The severe drop in numbers of all ages at -6 ft on transect 7 from 1970 to 1971 must have been partially, at least, a result of digging.

The shapes of the age-frequency histograms for *P. staminea* at Kiket Island are strikingly different from the classical pattern of exponentially decreasing numbers in each older year class. At Kiket, the variability in recruitment was sufficient to obscure the low mortality rate of younger clams (age 1 to 8) when looking at the age distribution from a sample taken during one year. Schmidt and Warme (1969) in one afternoon of sampling in Mugu Lagoon, California took 180 *P. staminea* and constructed a near-perfect negative exponential

age-frequency histogram. The population they were working with was obviously much different from that at Kiket Island. Recruitment must have varied but little from year to year and the mortality rate must have been high enough to mask any variations which did occur; just the opposite from the situation at Kiket Island. Perhaps this disparity is the result of a higher temperature regime and/or a high exploitation rate at Mugu Lagoon. The oldest clam taken in their study was 6 or 7 years old, whereas, in northern waters, ages greater than 10 are relatively common.

The effect of the variable recruitment at Kiket Island was to render age-frequency histograms from a one-time sample useless for determining the mortality rate as a function of age. With adequate sampling of a year class over several years, the mortality rate could be determined but in the absence of such records the "cumulative survivorship curve" was devised. By combining the results from all year classes, recruitment and mortality were averaged over several years and the resulting smoothed curves (Figs. 7-32 and 7-35) while not representing the decline in numbers of any one cohort, can be thought of as the mean expected pattern of the decline.

The log survivorship curve established by Schmidt and Warme (1969) from the death assemblage of *P. staminea* was considerably different from Fig. 7-31, forming a sigmoid pattern. They found that mortality was high early in life, decreased in middle ages (2-5 yrs), and then increased sharply with senesence. Part of this high early mortality rate may have been an artifact of their consideration of age 1 as the age at the end of the first full year, although they do not specify what their convention was in this important matter.

The linearity of the arithmetic survivorship curve implies that, for a given number of *P. staminea* in any location, there is an equal probability any given percentage of the total sample being in any age class from 1 to 9. For the entire sample the average per cent of the total number in each cohort is 11.6. In reality, the age-frequency distributions fall off sharply after age 8 as the mortality rate increases. Minor variations in this pattern were seen at different locations about the Island and production estimates were based on curves fitted to the data from the location in question.

7.5.3.4 Growth

The monthly samples taken during the 1972 season confirmed observations made during analysis of clams from the beach sampling that significant growth takes place from March through October. This suggests that growth of pelecypods in this part of Puget Sound may be dependent more on photoperiod, and hence food supply, than on temperature as one might expect. If this is the case, the results of Ansell (1969) working on *Mercenaria* in the thermal plume of a nuclear power plant in Scotland might apply. He found that these clams did indeed grow faster in the heated effluent than in nearby control areas during that period of the year when food was plentiful. However, in the winter months, when food was scarce, the maintenance requirements of *Mercenaria* in the warmer waters were higher and they tended to lose weight more rapidly than those in natural temperatures. In Puget Sound, where frequent periods of overcast limit primary productivity for much of the year, an increase in the ambient temperature might not greatly increase the over-all growth of many invertebrates.

The patterns of relative growth of *P. staminea* shown in Figs. 7-21 through 7-25 in most cases follow the same trends as were discussed above for distribution and abundance of invertebrates. That is, growth was significantly better at lower tidal levels and on the north side of the Island. Increased growth at lower tidal levels is obviously a function of increased immersion time and increased feeding time. However, some cost to the organism was also incurred with decreasing tidal level as growth was less rapid at -8 ft than at -6 ft (Figs. 7-24 and 7-25).

Several possible explanations exist. High siltation rates at -8 ft may adversely effect the efficiency of feeding. Perhaps the usual low transparency of water in Skagit Bay limits peak primary productivity to the upper one or two meters of the water column. Thus, those clams at -8 ft might be below the richest layer for a greater period of time than those at -6 ft. Another possibility is that *P. staminea* has adapted to the intertidal habitat to such a degree that a minimal emersion time is advantageous in some way. Many intertidal organisms do not thrive when submerged continuously.

Growth rate on the north side of the Island was faster at all levels and on all transects than on the south side. The most probable cause for this is

the slightly higher temperature regime and the higher degree of stability of environmental conditions in Similk Bay than in Skagit Bay proper. Although no estimations were made of primary productivity, it is probable that it was higher on the north side where currents and salinity fluctuations were less severe. The variable conditions on the south beaches might affect organisms directly by inhibiting some physiological function, or indirectly by inhibiting production of food organisms. The growth rate at transect 6 on the tip of Flagstaff Point approached that of transect 8. This can be readily linked to the rapid tidal flow through the pass between Kiket and Skagit Islands bringing a constantly replenished food supply to the clams. This is in line with the generalization of Frazer and Smith (1928*b*) that *P. staminea* grew better in areas with strong currents. Frazer and Smith also found that growth was usually slow in semi-enclosed bays where circulation was poor, but this was contradicted in the case of transect 8, probably because of the ameliorating conditions discussed above.

The construction of a Ford-Walford type plot of ΔL versus L_t to obtain parameters for the von Bertalanffy growth curves was done in two ways. The first method considered each $L_{t+1} - L_t = \Delta L$ on each clam in the population as a single observation, thus each clam would contribute (age - 1) degrees of freedom to the regression. In the second method the average $L_{t+1} - L_t = \Delta L$ for the whole population was taken, thereby limiting the df to 8 in a population of clams to 10 years of age. The advantage of the first method lay in the high df values when comparing between the parameters obtained from two different populations. The second method was considerably less cumbersome and the equations derived fit the observed data more closely. The probable reason for the better fit was the greater variance of the values of ΔL vs L_t for the more numerous early annuli. By using only the averages of these values, negative weighting was in effect applied to these lower values tending to decrease L_∞ and increase K. This acted to bring the predicted values closer to the actual (e.g., Figs. 7-23 and 7-34). Therefore, the first method was used in making t-tests for significant differences in growth rate between areas and the second was used in calculation of production rate after conversion to the growth in weight equation (3). The disparity between actual and predicted weight in Fig. 7-28A is to a large degree because the value of "weight at age i" is based on the average weight of all age i clams, even though

roughly one-half of them were taken during the summer sampling period after putting on considerable additional weight. The curve of actual weight versus age is also much less smooth than that for length. Since the production figures were based on the increase in weight from the start of one year to the start of the next it was desirable to take these values from the smoothed von Bertalanffy curve.

7.5.3.5 Production and Standing Crop

A number of potential sources of error exist in the calculations of annual production for the several areas at Kiket Island. The greatest chance for error in the expected number in a cohort certainly is in the age "0" class. Inspection of Fig. 7-28A, however, shows that the weight gain in the first summer is so low that even a two- or three-fold error in numbers of this cohort would not affect the total production by more than a few per cent. The majority of the production is from middle-aged clams and this is where the fit of the von Bertallanfy length equation to the raw data is best. The predictions of numbers of clams in each cohort are also best in this region.

The second greatest chance for error in numbers is for ages 9 and greater where the survivorship curves predict few or no clams. Obviously, where there are clams in these higher age groups, the curve (Fig. 7-28B) underestimates their contribution to the total production. In reality, then, the right hand tail of the production curve should approach the abscissa asymptotically rather than directly. If the survivorship curve had allowed for these older clams, the number of clams in the middle ages would have been reduced by an equal number. Since the change in weight in a year of older clams is somewhat less than that of middle aged clams (Fig. 7-28A), this error is on the conservative side. The net error in the total production however, is low, probably less than 5 per cent as a result of smoothing.

Techniques are available (Gulland, 1969) for estimation of the variance in the von Bertalanffy growth-in-weight equation. The confidence limits of the predicted numbers at each age in the arithmetic survivorship curves (Equations 5 and 9) are given in the FRD 312 regression. However, the validity of the latter confidence limit is questionable because of the unkown statistical distributions of the values for cumulative survivorship. The correction factor (S_i) introduced to allow for mortality in each cohort during the year

also has an unknown statistical distribution. Therefore, no effort was made to place confidence limits on the estimates of annual production.

The estimates of standing crop on the other hand were means of calculations of standing crop in each quadrat sampled at a given location. Standing crop was considered a normally distributed variable and confidence limits given in Tables 7-5 and 7-6 are legitimate. Use of wet weight including shell introduces some variability into the results but is commonly done when working with commercially important bivalves and is usually the figure recorded in production statistics. Additional variance was added by taking means from both winter and summer samples combined.

The order of magnitude for the confidence limits of the production figures obtained can be estimated using the limits given for standing crop and the ratio of standing crop to production. Confidence limits obtained in this way will probably be conservative, however, because of the variability in age structure at various locations.

The relatively high ratio (9.5) of standing crop to production for *S. giganteus* is typical of long-lived, slow-growing organisms. For *P. staminea* the ratio was well below this. The value from the north side (5.3), where production and growth were the greatest was inexplicably greater than on the south side (4.1). These ratio are comparable to those obtained in other studies studies on fresh and salt water bivalves. Negus (1966) reported ratios of from 4.9 to 7.8 for four species of unionid mussles in the River Thames with the higher values obtained for slower growing species. Kuenzler (1961) found a standing crop-production ratio of about 5 for *Modiolus demissus* in a Georgia salt marsh.

The standing crop of *P. staminea* and *S. giganteus* were estimated at 3,219 kg and 1,262 kg, respectively for the entire intertidal at Kiket Island (0 to -8 ft). Of the 4,481 kg for both species, about 10 per cent was on the south side of the island in densities so low as to discourage all but the most determined digger. Of the approximately 4,000 kg standing crop on the north side roughly 15 per cent occurred above the -4 ft contour in densities too low for use. This left an estimated 3,400 kg in the area between -4 ft and -8 ft on the north side in concentrations great enough for satisfactory recreational use, although the high cobble content of the substrate makes digging difficult over some of this area. Using a standing crop to production ratio of 6.5 for the two species in question (weighted by per cent

contribution to the total standing crop) the annual production expected in this area is about 525 kg. The realtionship of this annual production rate to maximum sustainable yield is uncertain because no measurements of digging effort and success were made. Although the area was subjected to moderate digging effort during the study it was concentrated below -6 ft and in areas not sampled. The stocks of *P. staminea* are virtually unexploited except in a few areas popular with the few diggers frequenting the island and the yield of this species could be increased greatly. *S. giganteus* is exploited rather heavily in two areas (the vicinity of transect 7 and between transects 5 and 6) yet the size of clams taken indicates that even there, the populations are not overexploited.

7.6 SUMMARY AND CONCLUSIONS

(1) Intertidal invertebrates have a high tolerance to acute thermal stresses and prediction of the long-term effects of slight thermal enrichment on intertidal ecosystems is very difficult. Therefore, it was felt that the best evaluation of the effects of a nuclear power plant at Kiket Island lay in securing adequate background information for comparison with future conditions.

(2) A species list was compiled of some 300 organisms, considerably more than in any other known intertidal study. The fauna at Kiket Island was found to lack several species important in Puget Sound proper but may have some species of infauna not present in the Sound. In general, the fauna was much richer on the north side of the Island than on the south, the result of greater insolation and greater influence of the Skagit River on the south side.

(3) The distribution, abundance and diversity of intertidal organisms were measured with repetitive sampling on 8 transects across the beaches and on parallel belt transects on the vertical cliffs at Kiket Island. Seasonality in the percentage of cover of algae was also recorded on the beach transects.

(4) Zonation patterns of intertidal organism on the beaches and cliffs were described and compared with each other and with zonation patterns described for two other Pacific Northwest locations. Factors affecting the

distribution patterns of intertidal organisms were discussed. It was felt that the relatively severe physical environment at Kiket Island limited the numbers of certain key biological competitors and predators, resulting in less distinct zonation patterns than is common on exposed shores.

(5) The age and growth of *Protothaca staminea*, the native steamer clam, and *Saxidomus giganteus*, the butter clam, were evaluated in depth. Marking experiments and systematic sampling established the validity of ageing these two important hardshelled clams through the use of concentric annular rings formed in the shell each winter.

Von Bertalanffy growth equations were fitted to length-at-age data from analysis of annular rings for both species. Tests for differences in growth rate of *P. staminea* at various locations about the island showed growth to be significantly better on the north side than on the south, probably the result of some combination of more stable (and higher) salinity, temperature, and/or primary productivity.

(6) Age-frequency distributions of *P. staminea* proved that recruitment of this species varied greatly from year to year and from place to place within a year. To overcome the variation in recruitment and the short duration of the study, mortality rates were estimated from a "cumulative survivorship curve," a plot of the number of clams age 1 or older, age 2 or older, etc. as a function of age. The linearity of this plot resulted from a low mortality rate for young and middle-aged clams and a much higher mortality rate for senescent clams. These curves were used to predict the average number of clams in each cohort expected at each location, thereby smoothing out irregularities in recruitment.

(7) Estimates of annual production of the two species were made based on the predicted average numbers of each cohort present during the year and the average annual weight gain for each cohort from a von Bertalanffy growth-in-weight equation. Average annual production of *P. staminea* in the intertidal area of Kiket Island from mean sea level to -6 ft was estimated at 4.34 g/0.25 m^2-yr on the south side and 45.6 g/0.25 m^2-yr on the north side. For the entire island the average was 28.8 g/0.25 m^2-yr compared with 7.2 g/0.25 m^2-yr for *S. giganteus* between -4 and -6 ft.

(8) Standing crop was estimated for the two species from the number and average weight of clams in each sample and standing crop to production ratios

were found to be in agreement with those of other bivalves. Total standing crop 3,319 kg for *P. staminea* and 1,262 kg for *S. giganteus* in the entire area between mean sea level and -8 ft. Production and standing crop of *P. staminea* was highest at the -4 and -6-ft tidal levels whereas for *S. giganteus* the peaks were at -6 ft or below. About 90 per cent of the total standing crop of *P. staminea* was on the north side of the Island. Stocks of both species appeared stable and well below the peak yield exploitation rate.

10) A high correlation was found between the location of areas with a high diversity and richness of invertebrates in general, and areas with high densities, good growth, and substantial production and standing crop of *P. staminea* and *S. giganteus*. It is presumed that the same environmental factors control all of these phenomea.

APPENDIX 7.A

The lack of detailed species lists of intertidal organisms in Puget Sound and the historical value of these records has been discussed in the text. This appendix provides such a list for Kiket Island. It also presents additional notes on the distribution, abundance, habitat and morphology of each species. The large number of species encountered in the various phases of the study of the intertidal zone at Kiket Island precluded presentation of the entire volume of information gathered on each species. Data on geographical range, feeding habits, etc. which are available in the literature were not reiterated. Range extensions and conditions unique to Kiket Island are noted. The species are presented by phyla and listed alphabetically within major taxa following the organization of Light (1970).

The "Reference Code" column contains a number referring to the references listed below which were used for identification of the species in question. The next section includes the highest and lowest level of occurrence (relative to mean sea level) of each species on the 8 beach transects and on the vertical transects ("Vertical"). At the end of this section the "Gen." column gives the same information for species not taken or not well represented in systematic sampling. Where only one figure is given for any of these sample areas, it represents the only level at which the species was found, although for rare species it may not describe the actual vertical distribution. Many species taken in general collecting below -6 ft were not encountered in systematic sampling and in many cases their level of occurrence is given as -8 ft. This is usually indicative of species whose distribution is continuous subtidally and many of them were, in fact, taken at somewhat lower levels where no precise level reference was available.

The next section lists the maximum density in No./0.25 m^2 of each species found on any transect ("Tr.") and level ("Lev."). Both the maximum at a given location averaged over all samples at that location and the maximum number from a single observation are included. Where the maximum from a single observation was based on a subsample the number is marked with an asterisk. Where it is based on a core sample it is marked with two asterisks.

Complete distributional data on many species of algae taken in systematic sampling are not included because separation of species of congenerics in the field was not possible (e.g., *Porphyra, Gigartina* and several filamentous Rhodophyta).

"Reference Code"	Reference
1	Anon., 1969
2	Kyte, 1969
3	Coe, 1940
4	Clemens and Wilby, 1961
5	Flora and Fairbanks, 1966
6	Hartman, 1968
7	Hyman, 1951
8	Personal communication with Mr. P. Lebednik
9	Schmitt, 1921
10	Light, 1970
11	Scagel, 1966
12	Smith, 1944
13	Personal communication with Dr. Pamela Roe
14	Personal communication with Dr. Robert Kohn
15	Personal communication with Dr. Karl Banse
16	Personal communication with Mr. Katharine Hobson
17	Berkeley and Berkeley, 1948, 1952
18	Hobson and Banse, in preparation
19	Quayle, 1970
20	Dunnill and Ellis, 1969
21	Keen, 1963
22	Oldroyd, 1924
23	Griffith, 1967
24	MacFarland, 1966
25	Personal communication with Dr. Dora Henry

"Reference Code"	Reference
26	Cornwall, 1970
27	Hatch, 1947
28	Barnard, 1954
29	Mayer, 1903
30	Personal communication with Dr. J. L. Barnard
31	Barnard, 1962

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island

	Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
I	Phylum Porifera																		
	Class Demospongiae																		
	Haliclona permallis (Bowerbank, 1866)	5						0 -4		0 -3	+2 -4		9	-4					-Encrusting in small patches on rock and barnacle shells.
	Haliclona sp. (yellow encrusting sponge)	5						+2 -4		-2 -3	+2 -4		9	-1 -4					-Encrusting in small patches on rock and barnacle shells.
II	Phylum Coelenterata																		
	Class Hydrozoa (unidentified hydroids)											-6 -8							-Only seen once in October, probably highly seasonal.
	Class Anthozoa (unidentified anemones)				+2 -6					-3	+1 -3								-Several smaller species sparsely distributed on rock & cobble.
	Anthopleura elegantissima (Brandt, 1835)	5									-2								-Rare at Kiket, very common in Puget Sound proper.
	Diadumene luciae (Verrill, 1866)	1	+2 -1		+4 -4	0 -3	+2 -2	+2		+4 -2	-4		4	+2	3.9	4	+4	23	-Common among mussels, barnacles.
	Epiactis prolifera (Verrill, 1869)	5										-6 -8							-Common on *Zostera* blades.
	Metridium senile Linnaeus, 1767)	5										-8							-Occasional on very low rocks.
	Metridium sp. A										-4	-6 -8							-Small many-tentacled form common esp. on low overhanging rocks, white.
	Tealia sp. A											-7 -8							-Large brown form occasional on low rocks.
III	Phylum Platyhelminthes																		
	Class Turbellaria																		
	Order Polycladida																		
	Notoplana	5	-2 -4	-2 -4	+2 -4	+1 -1	+2 -4	+4 -4	+2 -2	+4 -2	-4		6	+2	2.6	6	+2	18	-Abundant on cliffs, under rocks. Probably *N. segnis*.
	Polyclad (large green)		-4 -6	-2 -4	+4 -4	0 -3	+2 -2	0 -4	+1	0			5	-3	3.5	5	-3	20	-Less wide spread than *Notoplana*.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

	Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
IV	Phylum Nemertinea																		
	Nemertinea misc. unidentified		+1 -1	+2 -8	-4 -6	+2 -6	0 -8	+4 -6	+2 -6	+4 -8	+4 -4								-Several spp. common in all areas.
	Amphiporous	13	-3	-6		+4 -2	+3 -3	+2 -2	+4 -2	+2 -6			5	-1	12.5	5	-1	75	-Several spp. common in all areas.
	Carinoma mutabilis (Griffin, 1898 (?))	13	-5																-Large flat pale worm.
	Cerebratulus albifrons	3							-6										-Pale head. Light mauve anterior then abruptly darker posteriorly
	Cerebratulus sp. 1	13					-7					-8							-3 ft long flat bright red.
	Cerebratulus sp. 2	13		-8						-5			2	-8	1.0	2	-8	2	-Large pale worm. Maybe 2 spp.
	Cerebratulus sp. 3	13	-3 -5	-4 -8	-2 -6	0 -6	-1	-6	+2 -6	0 -6			1	-5	2.1	1	-5	8	-Small pale to white. Subanterior mouth. Maybe several spp.
	Emplectonema gracile (Johnston, 1837)	5		+4 -6	+2 0	+4 -4	+3 -3	+4 -6	+4 -4	+4 -2	+5 -3		9	+4	17.8	9	+1	100*	-Very abundant among mussels and barnacles.
	Lineus vegatus (Coe, 1931)	13								-8									-Similar to *E. gracile*, probably confused with it.
	Paranemertes peregrina (Coe, 1901)	5		-2 -6	-2 -4	+2 -4	-3	+2 -6	+4 -6		-2 -4		5	-3	1.7	5	-3	7	-Common on rocks and in low silty areas.
	Tubulanus sexlineatus (Griffin, 1898)	1										-8							-2 found in muddy crevice with *Thelepus* on Flagstaff Pt.-8 ft
	Zygonemertes spp.	13	+1	0 -2	-4	+4 -4		-2	+2 -4	0 -6	+4								-Uniform pale or dark grey-green also long slender white form.
	Nemertinea sp. 1		-3																-Long slender light tan species.
	Nemertinea sp. 2					-4													-Large pale round form.
	Nemertinea sp. 3	13						0	0 -4				7	-2	28.7	7	-2	343**	-Brown or green with longitudinal white stripe medially. Genus undescribed.
V	Phylum Sipunculoidea																		
	Golfingia pugettensis	14				-4	-3	-2 -6	-2 -4				7	-4	208	7	-4	458**	-Very abundant in low silty sediments especially on north side.
	Sipunculid sp. 1								-6	-5			7	-6	.3	7	-6	2	-Occasional in *Zostera* zone 12 digitate tentacles.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

	Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
VI	Phylum Annelida																		
	Class Polychaeta																		
	Family Ampharetidae																		
	Ampharete arctica Malmgren (?)	17							-6	-8									-Not good fit: anal papillae long branchiae long in limp chitinous tube - very long.
	Ampharete sp. A								-6										-12 anal papillae, 12 abdominal segments.
	Pseudosabellides littoralis (Berkeley)	17						-6											-One specimen good fit.
	Family Capitellidae																		
	Barantolla americana Hartman (?)	16	-1	-5 -4 -8	-4				-6	0 -8			8	0	14.3	8	0	172**	-Common especially in cleaner sediments. New for Wash., B.C.
	Capitella capitata (Fabricius)	17	-5	-4 -8	-2 -4			-2 -4	-6	-8	+1		3	-2	38	6	-4	172**	-Fairly common in variety of substrata including cliffs.
	Capitella sp. A	16		-4															-Not *C. capitata*, has limbate setae from 1st to 3rd segment only - cobble & gravel.
	Heteromastus filiformis (Claparede)	18	-3			-6				-8									-Silty mixed sediments also sand.
	Mediomastus sp. A	16	-3	-5 -2 -6		-2 -6		-4 -6	0 -6	-2 -8			7	-6	95.3	7	-6	286**	-Fairly common in variety of silty sediments. K. Hobson says may be new for area.
	Notomastus tenuis (Moore)	17	+1	-5 -2 -6	-2 -6	0 -6	-1 -5	-2 -8	-6	-1 -8			6	-6	49.3	6	-6	152	-Very wide spread. Ovigerous March and July, 1971.
	Family Cirratulidae																		
	Chaetozone berkeleyorum (Banse and Hobson)	15		-4				-6					2	-4	.3	2	-4	2	-Rare in mixed sediments.
	Cirratulus cirratus cingulatus Johnson	18		-6 -8									2	-6	1.0	2	-6	5	-3 subspecies separated on basis of first segment with neuropodial spines. Early in study all were called *C. C. spectabilis*.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Family Cirratulidae (cont'd.)																		
Cirratulus cirratus cirratus (Muller)	18			-4 -6	-2	-3	0 -8											
Cirratulus cirratus spectabilis (Kinberg)	18		-2 -8	-2 -4	-2 -6	0 -3	0 -8	+2 -6	+2 -8	-1		7	0	35.5	8	0	117	-Seen laying gelatinous masses of yellow eggs low on cliffs 1/71. Several adults intertwined.
Tharyx sp.		-5						-2 -6				7	-6	19.0	7	-6	114**	-May be new for area ∿ 140 segs. Smooth setae and inflated posterior.
Family Dorvilleidae																		
Dorvillea annulata (Moore)	17							-6	-8			7	-6	4.8	7	-6	57	-Silty mixed sediments.
Family Flabelligeridae																		
Pherusa papillata (Johnson)	18							-6	-8			8	-8	.5	7	-6	1	-Silty mixed sediments.
Family Glyceridae																		
Glycera americana Leidy, 1855								-6				7	-6	.2	7	-6	1	-Silty mixed sediments.
Glycera capitata Oersted	17		-2 -8		-2 -6	-3	-2 -8	-4 -6				2	-6	3.1	2	-6	7	-Common in clean and silty mixed sediments.
Hemipodus borealis (Johnson, 1901)	17	+1 -3	-2 -4	+2 -6	-2		0 -6	-2 -4	0 -8			6	-4	1.7	6	-4	9	-Common in clean and silty sand also in mixed sediments. Ovigerous, August.
Family Goniadidae																		
Glycinde polygnatha Hartman	15	+1 -5	-4 -8	-2 -6	-2 -6	-1 -5	-2 -6	-4 -6	-4 -8			7	-6	39.6	1	-5	114**	-Abundant in all soft bottom.
															7	-6	114**	Considerable variability in size, color.
Family Hesionidae																		
Ophiodromus pugettensis (Johnson)	18		-6			-3	-6	-6	-4 -8			7	-6	1.1	7	-6	3	Fairly common in silty surface muds over rock bench or mixed sediments. Ovigerous 7/71.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Family Lumbrineridae																		
Lumbrineris californiensis Hartman	16						-6											-Rare in silty mixed sediments.
Lumbrineris zonata (Johnson)	17		-4 -8	0 -6	+2 -4	+1 -3	0 -6	+2 -6	+2 -8			7	-2	28.3	6	-4	96	-Abundant in mid-lower barnacle zone.
Family Maldanidae																		
Maldanid sp. A									-8									-Thin parchment tube. Incomplete hooks like *Nicomache* but no recurving hairs.
Axiothella rubrocincta (Johnson)(?)	17							-6				7	-6	.2	7	-6	1	-Incomplete - 2 pre-anal achaetous segments. Pygidium with alternating long & short papillae, ventral longer and forked.
Nicomache personata Johnson	17		-4 -8		-6	-3		-6				2	-6	132.5	2	-6	286**	-Very abundant. Sandy tubes encrusting subsurface cobble.
Family Nephtydae																		
Nephtys caeca (Fabricius)	6	+1 -5	-2 -6	0 -6	-4 -6	0 -7	-2	-4 -6				4	-6	6.6	4	-6	13	-Abundant especially in sandy areas.
Nephtys caecoides Hartman	15				-6													-Prostomial pigmentation obscure but has dark transverse bars on anterior segments.
Nephtys ciliata Oersted	15		-8				-6 -8	-6	-8			8	-8	8.0	8	-8	12	-Common in *Zostera* zone.
Nephtys ricketsi Hartman (?)	15	-5																-Rare in silty sand. Close to *N. rickettsi* but could be *N. assignis*.
Nephtys sp. "B"					-6							4	-6	33.3	4	-6	172	-All tiny, with 2 eyes. Recurved interramal cirri from 4th segment. Probably juvenile.
Family Nereidae																		
Nereis brandti (Malmgren)	15	-1 -5										1	-1	.6	1	-1	3	-Common in sand and silty sand. Very large.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Nereis neoneanthes Hartman	15	+1 -5	-8				-8	-6				2	-8	.5	7	-6	3	-Exceedingly long worms. *Zostera* zone and higher in sandy areas. New for Wash.- B.C. area.
Nereis procera (Ehlers)	15	-5			-6		-6	-6	-8									-Lot of variability. Common on *Zostera* zone.
Nereis vexillosa Grube	5	-1	0 -8	+2 -6	-2 -6	-3 -5	+4 -8	+2 -6	+2 -6			2	-4	11.8	2	-4	40	-Abundant and wide spread. Becoming epitokous Mar.-July. To 16.5 cm long.
Platynereis bicanaliculata (Baird)	6		-4			-7	-6					6	-6	.3	6	-6	2	-Occasional on rock bench and in mixed sediments.
Family Opheliidae																		
Armandia brevis (Moore)	18		-4 -8	-4		-3	-6	-4 -6	-8			2	-6	4.8	2	-6	57**	-In silty surface layer over mixed sediments.
Euzonus williamsi (Hartman)	16	+1										1	+1	0.5	1	+1	1	-Common in narrow band on sandy beach. New for Wash. - B.C.
Ophelia limacina (Rathke)	18	+1 -1		-6								1	+1	0.8	1	+1	6	-Common in association with *Euzonus*. Also rare in low silty sediments.
Family Orbiniidae																		
Naineris dendritica (Kinberg)	18				0 -4		0 -6	0 -4	-1 -6			8	-3	56	8	-3	152	-Abundant in silty mixed sediment in lower barnacle zone.
Naineris quadricuspida	16	+1					+2 -4	0 -6				7	-0	213.9	7	-0	2052**	-Lacks 2 postsetal lobes, new for northeast Pacific.
Orbiniella n. sp.	16				0 -4		0	+2 -4	+2 -1			7	+2	167.5	7	+2	1373**	-Abundant in clean coarse sediments of upper barnacle zone. New species.
Scoloplos acmeceps Chamberlin	18	-1	-4 -6	-6	-2 -6		-2 -8	-6	-5 -8			1	-1	71.5	1	-1	229**	-Abundant in mixed seds. Also very small form abundant on Tr 1. May be different species.
Family Oweniidae																		
Owenia fusiformis delle Chiaje	17			-6	-4 -6	-5 -7	0 -6	-6				4	-6	14.2	7	-6	40	-Abundant in sand and silty sediments. Ovigerous 7/71.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Family Pectinariidae																		
Pectinaria granulata (Linné)	18		-3 -6		-4 -6	-1 -7	-6	-6	-8			8	-8	2.0	8	-8	4	-Common in *Zostera* zone. Tubes to 44 mm long.
Family Phyllodocidae																		
Eteone longa Fabricius	18		-6						+2 -4			2	-6	9.5	2	-6	114	-Mixed sand gravel and shell.
Eteone tuberculata Treadwell	18	-1			-6		-6											-Banse (1972) says not known since holotype.
Eulalia quadrioculata Hartman, 1936	18				0		-2		0 -2	-2 -4		9	-4	1.0	9	-4	5*	-Fairly common in rocky areas. Ovigerous 7/71.
Phyllodoce (Anaitides) maculata (L.)	17					-3	-4					6	-4	1.1	6	-4	12	-Locally numerous on rock cliffs. Lower barnacle zone.
Family Pilargidae																		
Pilargis berkeleyae Monro	15						-6		-4			8	-4	4.8	8	-4	57**	-Rare in mixed sediments.
Family Polynoidae																		
Arctonoë fragilis (Baird)	18										-8							-In ambalacral groove of *Evasterias*.
Harmithoë imbricata (Linné)	17	-3 -5	-4 -8		-4 -6		-6	-6	-8			2	-8	8.5	2	-8	9	-Common on and under rocks and shell in lower zones.
Hesperonoë complanata (Johnson)	17	+1 -5	-5				-6					1	-3	.6	1	-5	2	-Occasional in clean sand and mixed sediments.
Family Sabellidae																		
Chone gracilis (Moore)	17									-4								-Very tiny tubes growing on dead barnacle shells.
Eudistyllia polymorpha Johnson (?)	18							-6										-9 thoracic setigers. ∿ 38 branchia in partially coiled lobe.
Eudistyllia tenella Bush (?)	18										-8							-New for area but not well preserved. No eyes on branchiae.
Fabricia sabella (Ehrenberg)	17									-4								-Very tiny tubes on *B. glandula* shell.
Potamilla (Pseudopotamilla) occelata Moore	17								-2 -3	-3 -4		8	-3	1.0	8	-3	12	-Common on low or shaded cliffs.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Potamilla (Pseudopotamilla) reniformis (Linné)	17		-8				-6	-6				2	-8	.5				-Occasional in *Zostera* zone with tube protruding from surface.
Schizobranchia insignis Bush	17						-8	-6	0	-3 -1 -4		9	-4	3.3	8	-3	36	-Common on low or shaded cliffs. Also present in *Zostera* zone. To 130 mm body length.
Family Serpulidae																		
Chitinopoma groenlandica (Mörch)	17										-8							-Tiny sinuous calcareous tubes on *Pododesmus* shells.
Serpula vermicularis Linné	17										-8							-Occasional on very low rocks No. of lab. Abundant in Sound proper.
Spirorbis medius (Linné) (?)	17							-4				7	-4	1.8	7	-4	21	-Several on small rocks with bryozoans.
Spirorbis (Laeospira) variabilis Bush	17										-8							-Several on *Pododesmus* shell from very low cliffs north of lab.
Family Sigalionidae																		
Pholoe minuta (Fabricius)	17		-4 -8		-4	-3	-2 -8	-4 -6	-4 -8			2	-8	86.5	2	-8	172**	-Abundant in lower mixed sediments.
Pholoe sp. A	16							+2				7	+2	9.5	7	+2	57**	-Very small. Has longer blades on compound setae. Hobson says maybe *P. parva* or young.
Family Spionidae																		
Nerine cirratulus (delle Chiaje)	16	-5	-4 -5	-2	-4 -6	+1 -5		-4				3	-2	.7	2 2 3	-4 -5 -2	2	-Common in mixed sediments on south side.
Nerine foliosa (Audovin and Milne-Edwards)	17		-3 -5	-2	+2 -4	0 -1	-2 -6	0	0	-6		6	-6	2.1	6	-6	12	-Common in mixed sediments especially on south side. Eats *Ulva*? To 35 cm long.
Polydora (Pseudopolydora) kempi japonica (Imajima and Hartman)	16	-5						-6				7	-6	.2	7	-6	2	-Rare in *Zostera* zone.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Prionospio cirrifera Wiren	18							-6				7	-6	4.8	7	-6	57**	-Rare in *Zostera* zone.
Pygospio elegans	16			-6	-6			-6				3	-6	552.9	3	-6	5491**	-Very abundant in sand at MLLW. New for Wash. - B.C. area.
Rhynchospio arenicola Hartman	18			-6								3	-6	19.0	3	-6	114**	-Locally common in sand at MLLW. Sand encrusted tubes.
Spio filicornis pacifica Berkeley	17	-5	-5		-4			-6	-6			7	-6	4.8	7	-6	57**	-Flimsy membranous tubes with imbedded sand grains. Occasional.
Family Stygocapitellidae																		
Stygocapitella subterranea Knollner	16			+2								3	+2	9.7	3	+2	57**	-Rare in upper barnacle zone clear sediments. New for Pacific Ocean
Family Syllidae																		
Autolytus trilineatus Berkeley and Berkeley (?)	15						-2											-Rare on rock cliff.
Exogone lourei Berkeley and Berkeley, 1938	18		-6	-2	0 -6	-1	-4 -6	+2 -6	-1 -6	-4		7	-6	119.3	7	-6	1087**	-Very abundant especially in lower mixed sediments.
												6	-6	292.4	6	-6	1201**	
Syllis adamantea adamantea Treadwell	18		0 -2		+2 0	+1 -1	+4 -2	+4 0	0	+4 -2		9	+4	14.5	9	+3	50*	-Abundant in upper barnacle zone on cliffs and beaches.
															5	-1	40	
Syllis alternata Moore, 1908	18			+2		+3 +1	0 -6	-6	-6			7	-6	14.3	7	-6	114**	-Occasional on variety of substrata.
Syllis heterochaeta Moore	18	-5																-Rare in silty sand.
Syllis hyalina Grube	15						-6					6	-6	9.5	6	-6	114**	-Rare in silty sediments *Zostera* zone.
Syllis pulchra Berkeley and Berkeley	17				0				-2	+1 -4		9	-4	1.0	9	-4	5*	-Occasional on low cliffs. Others of uncertain ID.
Syllis sp. A								+4				7	+4	0.2	7	+4	2	-Like *S. hyalina* palps fused, 9-12 articles in dorsal cirri.
Syllis Sp. B								-4				7	-4	0.2	7	-4	2	-Rare. >> 50 articles in dorsal cirri. Blades too long for *S. pulchra*.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Family Terebellidae																		
Polycirrus sp.	15							-2	-4			8	-4	19.0	8	-4	114**	-Rare. Does not fit any species in keys.
Thelepus crispus Johnson	17						-2 -6	-2 -6	-2 -4	-4		7	-4	5.7	7	-4	23	-Common in silty sediments lower barnacle zone. Rare on cliffs.
Thelepus setosus (Quatrefages)	17		-2 -8	-4	-4 -6	-7	-4 -6		-4 -8			2	-8	27.0	2	-8	28	-Abundant in *Zostera* zone.
Class Oligochaeta																		
Oligochaete sp. 1			+2 -4		+2 -4			+2	+2 -2			4	0	429.0	4	0	5034**	-Very abundant in upper and middle barnacle zones. Bifed setae.
Oligochaete sp. 2		+3	0 -2	+4	+4	-1	+4	+4 -2	-4		+5	3	+2	95.3	4	+4	801**	-Very abundant in high tide drift detritus and in silty sediments in upper barnacle zone.
Oligochaete sp. 3			-2 -6	-2 -4	0	-1	-4 -6	0 -6	-3			7	-2	100.0	7	-2	972**	-Common in middle and lower barnacle zone.
II Phylum Priapuloidea																		
Priapulus caudata Lamark, 1816	7								-8									-Rare, low in *Zostera* zone, more common subtidally.
III Phylum Mollusca																		
Class Amphineura																		
Order Polyplacophora																		
Cyanoplax hartwegii (Carpenter, 1855)	1				+2 -4	-3	+2 -2		-2 -3	+4 -4		9	-4	5.8	6	0	8	-Common on lower cliffs and cobble.
															9	-2	8*	
																-4	8*	
Katharina tunicata (Wood, 1815)	5					+1	0 -4		-2 -3	+2 -4		9	-1	11.0	9	-2	23*	-Common on cliffs.
										0 -4						-1	23*	
Lepidochitona sp.	1																	-Occasional on cliffs. Some confusion with *Cyanoplax*.
Lepidopleurus sp.	1				-4							4	-4	0.2	4	-4	2	-Rare on subsurface cobble.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Mopalia ciliata (Sowerby, 1840)	1									-2								-Occasional on cliffs.
Mopalia lignosa (Gould, 1846)	1		-8		-6													-Occasional on cobble in *Zostera* zone and low cliffs.
Mopalia mucosa (Gould, 1846)	1						-4		-3	-4	-3 -8							-Occasional on lower cliffs and cobble.
Tonicella lineata (Wood, 1815)	1										-4 -8							-Common on low cliffs., e.g. north of lab.
Class Lamellibranchiata																		
Order Filibranchiata																		
Mytilus edulis Linnaeus, 1758	10	-1 -5	+2 -6	+2 -6	+4 -6	+1 -5	+4 -6	+4 -6	+4 -5	+5 -4		5	-3	255.6	6	+4	724	-Abundant - see text.
Pododesmus macroschisma (Deshayes, 1839)	5										-6 -8							-Common on low cliffs, e.g. north of lab.
Order Eulamellibranchia																		
Clinocardium nuttalli Conrad, 1837	10	-3 -5		-6	-4 -6	-5 -7	-4 -8	-4 -6	-8			2	-6	2.4	5	-7	6	-Common - see text.
Crassostrea gigas (Thunberg, 1793)	19		-4								-2 -4							-Occasional on cobble and rock bench along south side. Rare on north cliffs, occasional in mud east of Tr. 8.
Cryptomya californica (Conrad, 1837)	19	+1 -5	-3 -6	0 -6	-2 -6	-5	-2 -8	-2 -6	-6			1	-3	35.1	1	-3	65	-Abundant in *Upogebia* and *Callianassa* burrows, especially on Transect 1.
Hiatella arctica (Linnaeus, 1771 [?])	1						0 -4	-4	-2 -4	-2 -4		9	-3 -4	2.3 2.3	9	-3	8*	-Common especially nestled among dense *B. cariosus*.
Lasaea rubra Keen, 1938 (?)	1	-1	-6 -8		-2 -6	-5	-6	-6	-6			7	-6	305.0	7	-6	1087**	-May be *Mysella*. Abundant in *Zostera* zone.
Macoma incongrua (von Martens, 1865)	20		-4 -8	-6	-2 -6	0 -5	-4 -8	-4 -6	-6 -8			7	-6	6.3	7	-6	15	-Common in *Zostera* zone.
Macoma inconspicua (Broderip and Sowerby 1829)	20	+3 -5	0 -8	0 -6	-2 -6	+1 -7	-4 -6	-4 -6	0 -6			1	-5	902.3	1	-3	1773**	-Abundant especially on sandy beach at Transect 1.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Macoma inquinata (Deshayes, 1854)	20	-5	-2 -8	0 -6	0 -6 +1	-5	-2 -8	-2 -6	0 -8			4	-6	43.1	4	-6	190	-Same as *M. irus* - see text.
												8	-8	56.0				
Macoma nasuta Conrad (1837)	20	-1 -5		-2		-5		-6	-4 -8			4	-6	3.0	7	-6	15	-Common in *Zostera* zone.
Mya arenaria Linnaeus, 1758	19	-5	+2 0	0 -4	0	+1 -5	-2 -4	-4 -6	0 -6			8	0	1.3	8	0	15	-Locally common - see text.
Mya truncata Linnaeus 1758	19										-4							-Rare. One specimen from -4 ft in front of lab.
Protothaca staminea (Conrad, 1837)	19	-3 -5	-1 -8	0 -6	0 -6 +1	-5	0 -8	0 -6	-1 -8	-2 -3		7	-4	32.0	7	-4	60	-Abundant - see text.
Pseudopythina rugifera (Carpenter, 1864)	19						-6											-Rare. Commensal on *Upogebia.*
Saxidomas giganteus (Deshayes)	19	-5	-4 -6	-6	-2 -6	-1 -7	-2 -8	-2 -6	-5 -8			7	-6	3.3	4	-6	7	-Common - see text.
Tellina carpenteri Dall (?)	19				-6			-6				7	-6	0.3	7	-6	2	-Rare. May be *T. buttoni* but shape is closer to *T. carpenteri.*
Transennella tantilla (Gould, 1852)	1		-6		-6		-4 -6	-4 -6		-3		7	-6	57.1	7	-6	172**	-Common in *Zostera* zone.
Tresus capax (Gould)	19						-6	-6	-5			7	-6	1.2	7	-6	4	-Common in *Zostera* zone. Some may be *T. nuttalli.* Younger are more elongate (=*Schizothaerus*).
Venerupis japonica (Deshayes)	19						-2 -6		-1			8	-1	0.3				-Rare - see text.
Class Gastropoda Subclass Prosobranchia Order Aspidobranchia																		
Acmaea digitalis Eschscholtz, 1833	1			0	+4 0		+4	0 +4	0 +4	+1 +5 +2		9	+4	24.8	9	+4	55*	-Common on high cliffs.
Acmaea paradigitalis Fritchman, 1960	1		0 -6	-2 -4	+2 -4	+1 -3	+4 -6	+4 -6	+4 -4	+5 +1		9	+3	26.8	6	-2	228	-Abundant. Some younger *Acmaea* of other species may have been assigned here.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Acmaea pelta Eschscholtz, 1833	1		0 -6	+2 -4	+4 -4	-5	+4 -6	+4 -4	+4 -3	+4 -4		6	+2	14.8	6	0	89	-Abundant.
Acmaea persona Eschscholtz, 1833	1		+2 -2	+2	+4 -4	+3 -3	0	+4	0 +4 -1	+2 +1		7	+4	2.4	7	+4	6	-Common on boulders high on south side beaches. Also north cliffs.
Acmaea testudinalis scutum Eschscholtz, 1833	1		0 -6	0 -4	+2 -4	-3	+2 -6	-2 -6	+2 -3	0 -4		9	-4	21.3	9	-4	33*	-Abundant on lower cliffs and cobble.
Order Pectinibranchia																		
Assiminea sp. (?)	21				+4							4	+4	505.0	4	+4	1632**	-Very abundant locally in high silty gravel. In Oldroyd (22) *Syncera* also close.
Bittium eschrichtii Middendorff	1										-6 -8							-Common on low cliffs and rock benches.
Bittium sp.	21									-3								-Occasional. Probably *B. sanjuanense* or *B. challasiae.*
Lacuna sp.	21		-4		-4			-6	-8	+1 -4		9	-3	6.5	9	-3	15*	-Common on low cliffs and in *Zostera* zone. Taxonomy of local species not clear.
Littorina planaxis Philippi, 1847	10										+6 -0							-Some *L. scutulata* seem to fit this species in Light (10) all were counted as *L. scutulata.*
Littorina scutulata Gould, 1849	10		+2 -4	+2 -4	+4 -4	+3 -1	+4 -2	+4 0	+4 +1	+6 0		2	0	210.0	2	0	1300*	-Abundant on high rocks & cobble.
Littorina sitkana Philippi	10		+2 -5	+2 -4	+4 -4	+3 -1	+4 0	+4 0	+4 -4	+6 +2		2	0	345.0	2	0	1200*	-Same as *L. scutulata.*
Margarites lirulatus (Carpenter) (?)	23		-8				-6	-6		-4		2	-8	1.0				-Species fits Griffith (23) but are others which may be confused.
Odostomia sp.	22									-3 -4		9	-4	1.5	9	-4	13*	-Locally common on low cliffs several possible species.
Searlesia dira (Reeve, 1846)	10										-6							-Occasional on low cliffs & bench.
Thais emarginata (Deshayes, 1839)	23			-2 -4	+2 -4		+2 -4	0 -2										-Difficult to separate from *T. lima.* Common on middle and lower barnacle zones.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Thais lamellosa (Gmelin, 1792)	23	-5	-4 -8	-4	-4	-3	-6	+2 -6		-3 -4		7	-5	7.2	2	-5	19	-Common, especially in *Zostera* zone and low cliffs.
Thais lima Gmelin	23		-6		+2 -6		+2 -6		+1	-2 +4 +2		9	+4	1.3	9	+4	8*	-Common in middle and lower barnacle zones on cliffs & beaches.
Turbonilla aurantia (?)	1		-6 -8									2	-6	28.6	2	-6	229**	-Locally common in *Zostera* zone. Oldroyd (22) lists many other species.
Subclass Opisthobranchia Order Tectibranchia ?																		
Oncidiella borealis	14	+1			+2 -2	0 -3	+2 -4	+4	0 +4	-3 +2 -4		4	0	14.9	4	0	135*	-Abundant on *Fucus* especially. Taxonomic affinities uncertain.
Order Nudibranchia																		
Aeolidia papillosa (Linnaeus, 1761)	5										0							-Rare on rocks near Transect 4.
Anisodorus nobilis (MacFarland, 1905)	5										-2 -6							-Occasional on cliffs north side.
Cadlina marginata MacFarland, 1905 (?)	24										-6							-Rare on rocky point off Transect 7.
Diaulula sandiegenis (Cooper, 1862)	5						0				-4							-Rare on midtide rocks.
Doridacean sp. A										-1 -4		9	-4	1.0				-Small white form. Occasional.
Hermissenda crassicornis (Eschscholtz, 1831)	5										-6 -8							-Occasional on *Zostera* blades. More abundant subtidally.
Onchidoris bilamellata	14			-4	-4		+2 -4	-2 -4	+2			4	-4	0.8	4	-4	9	-Common midtide rocks and beaches. Laying eggs 3/21/71.
IX Phylum Arthropoda Class Cirripedia																		
Balanus cariosus (Pallas, 1788)	26		-4			-3	+2 -4	+4	-6 +4	-5 +4 -4		9	0	1138	9	0	2575*	-Abundant on north cliffs.
Balanus crenatus Bruguière, 1789	25	-5	-4 -8	-4 -6	0 -6	-3	-7 -4	-8 -4	-6	0 -8 -3 -4		6	-6	954	6	-6	5193*	-Abundant in *Zostera* zone and common low on cliffs.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Balanus glandula Darwin, 1854	26	+1 -3	+2 -6	+4 -6	+4 -6	+3 -7	+4 -6	+4 -6	+4 -6	+6 -4		9	+4	6570	9	+4	10925*	-Abundant in barnacle zones.
Chthamalus dalli Pilsbry, 1916	26		+2 -3	+2 0	+4 +2		+4 0	+4 -2	+4 0	+5 +1		9	+4	138	9	+4	735*	-Abundant in upper barnacle zone.
Class Malacostraca Subclass Peracarida Order Chelifera																		
Leptochelia dubia Krøyer	27		-8		-6			-4 -6	-8			2	-8	200	2	-8	400*	-Locally abundant in *Zostera* zone.
Order Isopoda																		
Cirolana kincaidi Hatch, 1947	27	-1																-Rare in sand. Possibly stranded by tide.
Gnorimosphaeroma oregonensis oregonensis (Dana, 1855)	1	-5	+2 -6	+2 -6	+4 -4	-1 -3	-2 -6	+4 -6	+2 -3	+2 -4		2	-4	87.2				-Abundant and widespread.
												6	-4	88.7	6	-4	725*	
Idothea (Pentidotea) wosnesenskii (Brandt, 1851)	1	-5			+2 0	-1	+2 -2	-2		+2 -4		9	+2	3.8	6	0	15	-Common in association with *Fucus*.
															9	+2	15*	Carrying eggs March through August.
Ione cornuta Bate	27	-1 -5																-Occasional. Parasitic on *Callianassa*. With eggs in 1/71.
Ligia pallasii Brandt, 1833	27						+4	+4		+6 +1		9	+5	16.6	9	+5	48*	-Abundant, high on cliffs.
Munna kroyeri (Goodsir)	27						0			-1					6	+4	22	-Rare on cliffs. Tiny. 3/71 with eggs.
Phryxus abdominalis Krøyer	27					-1												-Common on abdomen of *Heptacarpus*.
Phyllodurus abdominalis Stimpson, 1857	27		-4				-6											-Common on abdomen of *Upogebia*. 3/71 with eggs.
Pseudione giardi Colman, 1898	27					0 -3	0 -6	-2 -6	0 -2	+2 -4					6	-2	6	-Common on *Pagurus* (2 spp.). Ovigerous Dec., May, July.
Synidotea angulata Benedict	27								-8									-Rare in *Zostera* zone.
Order Amphipoda																		
Allorchestes angustus Dana, 1854	28	-1 -3					+4?					1	-1	23.8	1	-1	228**	-Occasonal in sand on Transect 1.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m² Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Ampithoe lacertosa (Bate, 1858)	28						-8	-6										-Rare in *Zostera* zone. Large, green.
Ampithoe simulans Alderman, 1936	28		-4 -8	-2	0 -4	+1 -3	+2 -6	+4 -6	+4 -2	+4 -4		4	-4	15	4	-4	114**	-Abundant and wide spread.
Ampithoe valida (S. I. Smith, 1873)	28				-4					+1					6	-4	125*	Makes cocoons on cliffs. -Rare on cliffs and beaches.
Anisogammarus confervicolus Stimpson, 1857)	28	-3 -5			0			+2	+2	-2		9	-2	1.0	9	-2	5	-Occasional in midtide range on rocks.
Anisogammarus pugettensis (Dana, 1853)	28	-5	-8		-4		-6	-6	-2 -8			7	-6	201.0	7	-6	1087**	-Abundant in *Zostera* zone in summer.
Calliopius laeviusculus (Krøyer, 1838)	28						-6											-Rare intertidally, common offshore at Kiket.
Caprella laeviusculla Mayer, 1903 (?)	29		-8	-6	-4	+1	-6	-4 -6				3	-6	9.5	2	-8	57	-Locally abundant in *Zostera*
Corophium acherusicum (Costa, 1857)	28		-4 -8			-7	+4 -2	+4 -6		-3		7	-6	95.6	3 7	-6 -6	57 744	zone, or blades of *Zostera*. -Locally abundant in low sandy areas. Also on upper cliffs! Seems to be same species.
Eusirid sp. A					0			+2										-Unable to key.
"Eusirid new genus near *Atylopsis*"	30				+4 -2	0 -3	+2 -4	+4 0	-4	0 +3 -3		7	0	66.8	7	0	686**	-Abundant on cliffs in barnacle zones.
Gammarid sp.			-4															-Several unidentifiable young and females.
Heterophoxus oculatus (Holmes) (?)	1							-4										-Rare - only species listed in Friday Harbor Keys (1) but others probably present.
Hyale plumulosus (Stimpson, 1857)	10		+2 -3	+2 -2	+4 -4	+3 -1	0	+4 -2	+2	0					2	-2	57	-Abundant on upper beaches under cobbles.
Hyale pugettensis (Dana, 1853)	10		-6		+4 -2		+2 -0	+2	+1	+3		4	-2	62.0	4	-2	744**	-Abundant on rocks and cobble beaches. Ovigerous 3/71.
Maera inaequipes (Costa, 1851) (?)	28		-8									2	-8	1.0	2	-8	2	-Rare *Zostera* zone clear pink female.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Melita lagunae	31				0													-Rare - may be new for Wash.
Orchestia traskiana Stimpson, 1857	28	+3 -5		+4	+4 +2			+4 -6		+5		4	+4	1344	4	+4	16130**	-Very abundant in drift algae and detritus.
Pontogeneia inermus (Krøyer, 1838) (?)	28				-2 -6		-8 -6											-Occasional *Zostera* zone.
Subclass Eucarida Order Decapoda Tribe Carides																		
Crago alaskensis elongata (Rathbun) (?)	9							-6										-Rare. Carina on 5th segment of abdomen not visible.
Crago nigricauda (Stimpson, 1856)	9	-3		-2	-2		-4 -6					7	-4	0.3	7	-4	2	-Occasional in low wet surface silt.
Heptacarpus sitchensis Holthius, 1947?	1					+1 -3		-4				5	+1	1.3	5	+1	5	-Common in tiny tidepools in rocks.
Heptacarpus stimsoni Holthius, 1947?	1							-6										-Same as *H. sitchensis*.
Tribe Brachyura																		
Cancer magister Dana, 1852	5	-3 -5		0 -4			-2	-6				3	-4	0.4				-Occasional small individuals burrowed into sediments.
Cancer oregonensis (Dana)	5										-8							-Occasional low on rocky point off Transect 7.
Cancer productus Randall, 1839	5		-8				-6 -8	-6	-8			7	-6	0.4	6	-6	2	-Common in *Zostera* zone, especially smaller individuals.
Hemigrapsus nudus (Dana, 1851)	5		+2 -5	+4 -4	+4 -4	+3 -3	+4 -6	+4 -4	+4 -3	+4 -4		7	0	35.9	7	0	148	-Abundant upper beaches and cliffs.
Hemigrapsus oregonensis (Dana, 1851)	5	-1 -5	-1 -8	+2 -4	+2 -4	+1 -3	+2 -8	+2 -6	+2 -6	-1 -4		3	-1	23.2	5	-1	69	-Abundant lower beaches and cliffs.
Lophopanopeus bellus (Stimpson)	5							-6										-Rare in silty surface layer of *Zostera* zone.
Oregonia gracilis Dana	9										-8							-Rare on rocks of Transect 7.
Pinnixa faba (Dana, 1851)	1						-6	-6				7	-6	0.4	7	-6	2	-Commonly found in all large *Tresus*.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Pinnixa littoralis Holmes, 1895	1		-8				-4	-6				7	-6	0.7	7	-6	5	-Common, also in association with *Tresus*.
Pinnixa schmitti Rathbun	1	-3 -5				-7	-6	-6	-5 -8			6	-6	0.3	6	-6	2	-Occasional, probably in tubes of larger nereids.
Pugettia gracilis Dana, 1851	9										-8							-Rare on rocks at Transect 7.
Pugettia producta (Randall, 1839)	9										-8							-Occasional in *Laminarians* on lowest rocks at Transect 7.
Scleroplax granulosus (Rathbun)	1	-3 -5	-5 -6		-2 -6	-5	-6								2	-6	2	-Common especially in sandy areas probably in tubes of large burrower. Ovigerous Apr. & May.
Telmessus cheiragonus (Tilesius)	5			-6		-7		-6	-6			7	-6	0.3	7	-6	2	-Occasional in *Zostera* zone.
Tribe Anomura																		
Callianassa californiensis Dana, 1854	5	+1 -5	-6	-6	-6		-6 -8					1	-1	5.0	1	-3	7	-Abundant in sandy areas and common in *Zostera* zone. Ovigerous - June.
Pagurus beringanus (Benedict)	1										-8							-Occasional on lowest rocks off Transect 7.
Pagurus granosimanus (Stimpson, 1859)	1						-6	-4 -6				7	-6	0.5	7	-6	3	-Occasional in *Zostera* zone. Ovigerous, December, 1970.
Pagurus hirsutiusculus (Dana, 1851)	1		+2 -8	+2 -6	+4 -6	+1 -3	+2 -6	+4 -6	+4 -3	+3 -5		2	-3	140.2	3	-2	575*	-Abundant and widespread. Ovigerous, Jan. through July.
Upogebia pugettensis (Dana, 1852)	5	-3 -5	-1 -6	-2 -6	-2 -6	-1 -5	-4 -8	0 -6	-1 -8			2	-5	2.0	2	-6	5	-Abundant in coarse mixed sediments and in silty sand.
Class Chilopoda Centipede					+4 -2	+3	+4 -4	+2 0	4 -1			4	+4	19.3	4	+4	229**	-Abundant in upper barnacle zone infauna.
Class Insecta																		
Class Arachnida																		
Family Halacaridae	10																	-Occasional on rocks.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
X Phylum Bryozoa					-4			-4	0 -3									-Several species occasional on low rocks and cobble
XI Phylum Phoronidea																		
Phoronopsis harmeri Pixell	5	-3 -5	-4 -8	-2 -6	-4 -6	-5 -7	-4 -6	-2 -6	-4 -8			4	-6	2.7	4	-6	7	-Common in *Zostera* zone. Stiff sand tubes.
XII Phylum Brachiopoda																		
Terebratalia transversa (Sowerby, 1846)	22							-4										-Rare in silty mixed sediments.
XIII Phylum Echinodermata																		
Class Asteroidea																		
Evasterias troschelii (Stimpson, 1862)	1										-8							-Occasional on *Zostera* flats.
Henricia leviuscula (Stimpson, 1857)	5										-8							-Rare on Flagstaff Point bench.
Leptasterias sp.	5		-3				0 -4	-4	0 -3	+3 -4		9	-4	12.5	9	-3	25*	-Abundant on shaded cliffs. Probably *L. hexactis*.
Pisaster brevispinus (Stimpson, 1857)	1						-8											-Occasional on *Zostera* flats.
Pisaster ochraceus (Brandt, 1835)	1										-6 -8							-Common on lowest cliffs north of labs and Transect 7.
Pycnopodia helianthoides (Brandt, 1835)	5										-8							-Seen in water off Transect 7. Not taken intertidally.
Class Ophiuroidea																		
Diamphiodia occidentalis (Lyman) H. B. Fell, 1962	2	-5			-6	-7	-6 -8	-6	-8			7	-6	11.9	7	-6	29	-Abundant in *Zostera* zone near Transect 7.
Ophiuroid sp. A								-6	-8			7	-6	14.3	6	-6	114**	-Common tiny white ophiuroid in *Zostera* zone on north side.
Class Echinoidea																		
Strongylocentrotus drobachiensis (Muller)	5		-4	-2	-2						-4 -6							-Rare amongst cobble on south side. Occasional in crevices on north cliffs. Generally small.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Class Holothuriodea																		
Cucumaria miniata Brandt, 1835	1										-6 -8							-Common under rocks and in cracks on low cliffs and benches.
Cucumaria sp.	1										-8							-Small white species. Under rock on Flagstaff Point. Rare.
Leptosynapta sp.	1						-2	-6	-4	-6 -4 -6		8	-6	5.5	8	-6	14	-Common in silty sediments in lower barnacle and *Zostera* zones on north side. With young in mesentery tubules, 12/70.
Stichopus californicus (Stimpson, 1857)	1										-8							-Rare in lowest *Zostera* zone.
XIV *Phylum Chordata* *Subphylum Urochordata*																		
Amaroucium californicum Ritter and Forsyth, 1917 (?)	5									+2 -4								-Common encrusting in small colonies on north cliffs.
Boltenia villosa (Stimpson, 1864)	5										-7							-Rare on lowest rocks north of lab.
Subphylum Vertebrata																		
Ammodytes hexapterus Pallas, 1811	4				-6													-Occasional in low coarse sediments and sand.
Anoplarchus purpurescens Gill, 1861	4										-8							-Occasional under very low rocks on Flagstaff Point.
Apodichthys flavidus Girard	4							-6										-Occasional under rocks and in moist surface layer in *Zostera* zone.
Clevelandia ios (Jordan and Gilbert)	4	-3										1	-3	0.2	1	-3	1	-Occasional in burrows of *Callianassa* or *Upogebia* on sandy beach.
Clinocottus acuticeps (Gilbert, 1895)	4				+4													-Common in tide pools and at water's edge.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

	Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
	Oligocottus maculosus Girard	4							-4										-Common in tide pools and moist pockets under rocks.
	Pholis laeta (Cope) 1873	4										-8							-Occasional under very low rocks on Flagstaff Point.
	Pholis ornata (Girard, 1854)	4			-6			-6					3	-6	0.2				-Occasional under rocks or perhaps in burrows of *Callianassa*.
XV	Lichen																		
	Verrucaria sp.										+6								-Forms black band above upper barnacle zone.
XVI	Algae																		
	Class Chlorophyceae																		
	Cladophora microcladiodes Collins (?)	8			-6			-6				-6							-Green tufts on low rocks of Transect 6 and elsewhere.
	Cladophora sp.								+4	+2	+4 +1 +1 -4								-Thick mat below top of *Fucus* band on well shaded cliffs at Transect 8.
	Enteromorpha crinita (Roth) J. Agardh	8	-3		-8	-6	-7	-6	-6	-6									-Long "ropes" in *Zostera* zone.
	Enteromorpha intestinalis (L.) Link (?)	12								+4		+4	0						-Locally abundant in upper areas moistened by freshwater runoff.
	Gomontia polyrhiza (Lagerheim) Barnet & Flahault	8										+5	+4						-Greenish hue on barnacle shells on shaded upper cliffs.
	Ulva lactuca Linnaeus	12	-1	-5 -1	-8	+2	-6	+4 -6	+3 -7	+2 -8	+4 -6	+4 -8	+4 -4						-Seasonally abundant and widespread.
	Class Phaeophyceae																		
	Alaria sp.											-8							-Common on very low bench, Flagstaff Pt. Probably *A. nana* or *A. marginata*.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Costaria costata (Turner) Saunders	12								-8		-7 -8	8	-8	50	8	-8	100	-Locally abundant in *Zostera* zone and Flagstaff bench.
Cystoseira geminata C. Agardh	8										-8							-Occasional on Flagstaff Point bench.
Delesseria decipiens J. G. Agardh	8										-8							-Occasional on Flagstaff Point bench.
Desmarestia aculeata (Linnaeus) Lamouroux	8										-6							-Rare on Flagstaff Point. May have drifted in.
Desmarestia herbacea (Lamouroux)	8										-8							-Flagstaff Point.
Desmarestia viridis (Müller) Lamouroux	8										-8							-Flagstaff Point.
Ectocarpus ellipticus Saunders	8										+2 -4							-Epiphytic on *Fucus* in lower range.
Fucus distichus Linnaeus emend Powell	8		0 -6	+2 -4	+4 -4	+3 -3	+4 -6	+4 -6	+4 -3	+5 -4								-Abundant and widespread on rocks.
Laminaria groenlandica Rosenvinge	11										-8							-Very low rocks off Flagstaff Point.
Laminaria saccharina (Linnaeus) Lamouroux	8		-8				-6				-6 -8							-Common on low cliffs and cobble in *Zostera* flats.
Leathesia difformis (L.) Areschoug	12								+2 -2									-Rare on well shaded cliffs also epiphytic on *Fucus*.
Nereocystis luetkeana (Mertens) Postels and Ruprecht	12										-8							-Occasional on very low bench on Flagstaff Point.
Petalonia debilis (C. Agardh) Derbes et Salier	8										-4 -8							-Occasional on low cliffs on north side.
Sargassum muticum (Yendo) Fensholt	8										-6 -8							-Occasional on low bench Flagstaff Point.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr. Lev. No.	Single observation Tr. Lev. No.	Notes
Scytosiphon lomentaria (Lungbye) J. Agardh Class Rhodophyceae	12						-6		+2					-Rare on north side cliffs.
Antithamnion glanduliferum Kylin	8										-6			-Flagstaff Point beach.
Bangia fuscopurpurea (Dillwyn) Lungbye	8										+2 -2			-Common on upper cobble and on the marine railway in front of the lab.
Callithamnion acutum Kylin	8									-4				-North cliffs.
Callithamnion pikeanum Harvey	8									0				-North cliffs.
Endocladia muricata (Postels and Ruprecht) J. G. Agardh	12						+2	+2						-Upper cliffs.
Gigartina corymbifera (Kützing) J. G. Agardh	8										-8			-Low on Flagstaff Pt. bench.
Gigartina papillata (C. Agardh) J. Agardh	8									+4 -4				-Abundant and widespread small thallic probably in this species.
Halosaccion grandiforme (Gmelin) Ruprecht	12						+2 -6			+3 -4				-Abundant on north cliffs but did not form a distinct zone, as on open coasts.
Hildenbrandia prototypus Nardo	8		+2 -6		+4 +2		+4 -4	+4 -4	+4 0	+4 -4				-Abundant on high cobble and cliffs.
Iridaea cordata (Turner) Bory (?)	8										-8			-Low on Flagstaff Point bench.
Iridaea heterocarpa Postels & Ruprecht	8				+2	-1	+2	+2 -6	+4 +1	+4 -4				-Abundant on north cliffs.
Lithophyllum decipiens (Foslie) Foslie	8										-4			-Occasional in crevices low on north cliffs.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Lithophyllum neofarlowii Setchell et L. R. Mason	8									-2								-Same as *L. decipiens*.
Microdladida borealis Ruprecht	8										0 -4							-Common in lower barnacle zone on north cliffs.
Odonthalia floccosa (Esper) Falkenberg	8						+2 -6	+4	+4	0 +3 -4								-Common on north cliffs but not co-dominant as reported by Nybakken (1969)
Platythamnion pectinatum Kylin	8						-6											-Flagstaff Point bench on rocks and gravel.
Polyneura latissima (Harvey) Kylin	8										-8							-Flagstaff Point rocks.
Polysiphonia paniculata Montagne	8										-4 -6							-On gravel beach near lab. and in tide pool in Flagstaff Point bench.
Porphyra abbottae Krishnamurthy	8										-5 -6							-Flagstaff Point near Transects 4 and 5.
Porphyra perforata J. Agardh	8										0							-On marine railway in front of lab.
Porphyra sanjuanensis Krishnamurthy	8										0							-Same as *P. perforata*.
Porphyra sp.											+4 -6							-Above three species common and widespread but species identification not made.
Prionitis lyalli Harvey	8										-6							-Tide pools on Flagstaff Point bench.
Ptilota filicina (Farlow) J. G. Agardh	12										-6 -8							-Abundant on low rock benches of Flagstaff Point.
Rhodochorton tenue Kylin	8							+4			+7 +5							-Thick tufts and mats in high shaded crevices on north cliffs.

Appendix Table 7.A-1. Species list, distribution, and notes for all intertidal macroorganisms taken at Kiket Island - continued

Species	Reference code	Distribution (Highest and lowest level for each area of occurrence) 1	2	3	4	5	6	7	8	Vertical (9)	Gen.	Maximum density no./.25 m^2 Average Tr.	Lev.	No.	Single observation Tr.	Lev.	No.	Notes
Rhodymenia pertusa (Postels & Ruprecht) J. Agardh (?)	11										-8							-Low on rocks Flagstaff Point.
Rhodymenia stipitata Kylin	8										-8							-Same as *R. pertusa*.
Smithora naiadum (Anderson) Hollenberg	8										-8							-Common epiphyte on *Zostera* blades.
XVII Seed Plants																		
Zostera marina L.	11	-5			-6	-7		-6			-6						-8	-Abundant in *Zostera* zone and subtidally.

8.0 SUBTIDAL ECOLOGY

by

D. L. Mayer

8.1 INTRODUCTION

8.1.1 General

The effect of thermal enrichment of a shallow bay will be expressed throughout a wide range of biological and ecological processes. In order to gain the capacity to recognize and interpret these effects and predict them, it is necessary to understand the ecological processes. These processes are numerous and in many cases unmeasurable; therefore representative portions of the ecosystem are usually chosen for study. The subtidal ecology of Kiket Island was treated in such a manner.

Portions of the subtidal ecology were chosen for study based on the extent to which they represented the majority of the subtidal realm around Kiket Island. The selected portions were related to one another by an autecological study of a single resident species, the Dungeness crab, *Cancer magister*. The crab was selected for two considerations. It has been proven to be a well-developed link to man and was thought to be a dominant member of the subtidal community.

The effect of the power plant was expected to be most publicly visible through an effect on some species of commercial or recreational value and both locally and regionally the Dungeness crab is such a species. Although the relationship of *C. magister* to the benthic community was unknown, it was suspected to have a measurable predatory influence on the benthic infauna assemblages. Secondarily, the crab proved to be easily adaptable to experimental design, readily obtainable, and relatively little studied.

8.1.2 Description of the Study Area

The study area extended from 20 ft (6.1 m) (MLLW) to a depth of approximately 90 ft (27.4 m). Much of the region is a shallow bay with an average depth of 25-30 ft (7.6-9.1 m). Similk Bay is the main geographical division.

A smaller arm of Skagit Bay lies to the south of Kiket Island. The steep bottom slope at the mouth of Similk Bay tends to separate it from the deeper region of the area. The basins on the south and north sides of Skagit Island deepen abruptly from the narrow shores to an average depth of 60-70 ft (18.3-21.3 m). The studies were concentrated in the shallow regions on the assumption that these areas were representative of the areas with the greatest potential for thermal degradation. The subtidal study was further limited to the level mud bottom below the shallow eelgrass zones.

Similk Bay has a nearly featureless soft mud bottom, relieved by a single scour hole on the north side of Kiket Island. The currents and water quality measurements are described in Section 4.0 of this report and will be discussed here only briefly.

The discharge from the Skagit River advects large volumes of high salinity water from the area south of the river delta toward Kiket Island. The two water masses remain stratified until they reach Deception Pass. On an ebbing tide, the water is stratified on the inland side of the Pass and thoroughly mixed on the seaward side. A reverse in tide reverses the mixing direction. The deep saline water passes through the study area in the channels between Whidbey, Hope, and Skagit Islands. The water in Similk Bay is normally lower salinity surface water (*see* Section 4.0). On occasion, high salinity intrusions occur in channels along the north and south sides of the Bay. Average weekly salinities ranged from 14.5 ^{o}/oo to 29.7 ^{o}/oo with a minimum observation of 10 ^{o}/oo in April 1972. The seasonal trends in salinity throughout the study period of 1970-1972 are illustrated in Figs. 4-2 and 4-3. The temperatures were constantly recorded during this period at the surface and 25 ft (7.6 m) on the north and south sides of Kiket Island, and the seasonal changes are illustrated in Fig. 4-1.

As will be pointed out in the following report, there is a paucity of information on the shallow-bay benthic ecology of Puget Sound. Recent work by Lie (1969) expanded our knowledge of the Puget Sound benthos.

8.2 THE DUNGENESS CRAB STOCK AND FISHERY IN THE VICINITY OF KIKET ISLAND

8.2.1 Background and Objectives

Recreational and commercial harvest of crab in the Kiket Island area dates back to at least 1915. Statistical records prior to 1943 are either incomplete or nonexistent. Prior to 1950 crabbing was conducted by ring-net gear, but since then most crabbing has been by the standard commercial crab pot. Most of the commercial catch is landed in the Anacortes area, where it is sold locally or shipped frozen. The landings from 1943 through 1971 for Anacortes and Skagit Bay (Washington State Department of Fisheries, 1965; Ward, personal communication) are summarized in Fig. 8.2-1. The majority of crabs landed from Similk Bay are recorded as catches from Skagit Bay. Landings from Skagit Bay declined severely during the period 1944-1957, and landings in Anacortes in nearly an identical manner ten years later, 1954-1957. These statistics are strongly related to the coastal crab landing statistics (Anon, 1966) (adjusted to pounds of crabs per pot by the author) during the same timespan (Fig. 8.2-2). Peaks in the landings from Skagit Bay lagged approximately 1 year behind peaks in the coastal landings. The relationship may be due either to a recruitment of Puget Sound stocks from coastal larval production or to the occurrence of favorable environmental conditions at approximately the same time in both locations. It is apparent that during the past 30 years fishing effort has shifted from Puget Sound to the coast, but the similarity in the catch fluctuations between the two areas suggests that the trends seen (Fig. 8.2-1) represent real population changes. The crab populations in the Skagit Bay and Anacortes areas based on landings from these areas are smaller and less productive than in the pre-1950 period.

A study was conducted of the crab stock and fishery in the vicinity of Kiket Island for the purpose of gathering baseline information on the year-round abundance of crabs. This information was obtained from tagging studies, catch per unit of effort (CPUE) of test fishing, and a questionnaire survey of recreational and commercial fishermen.

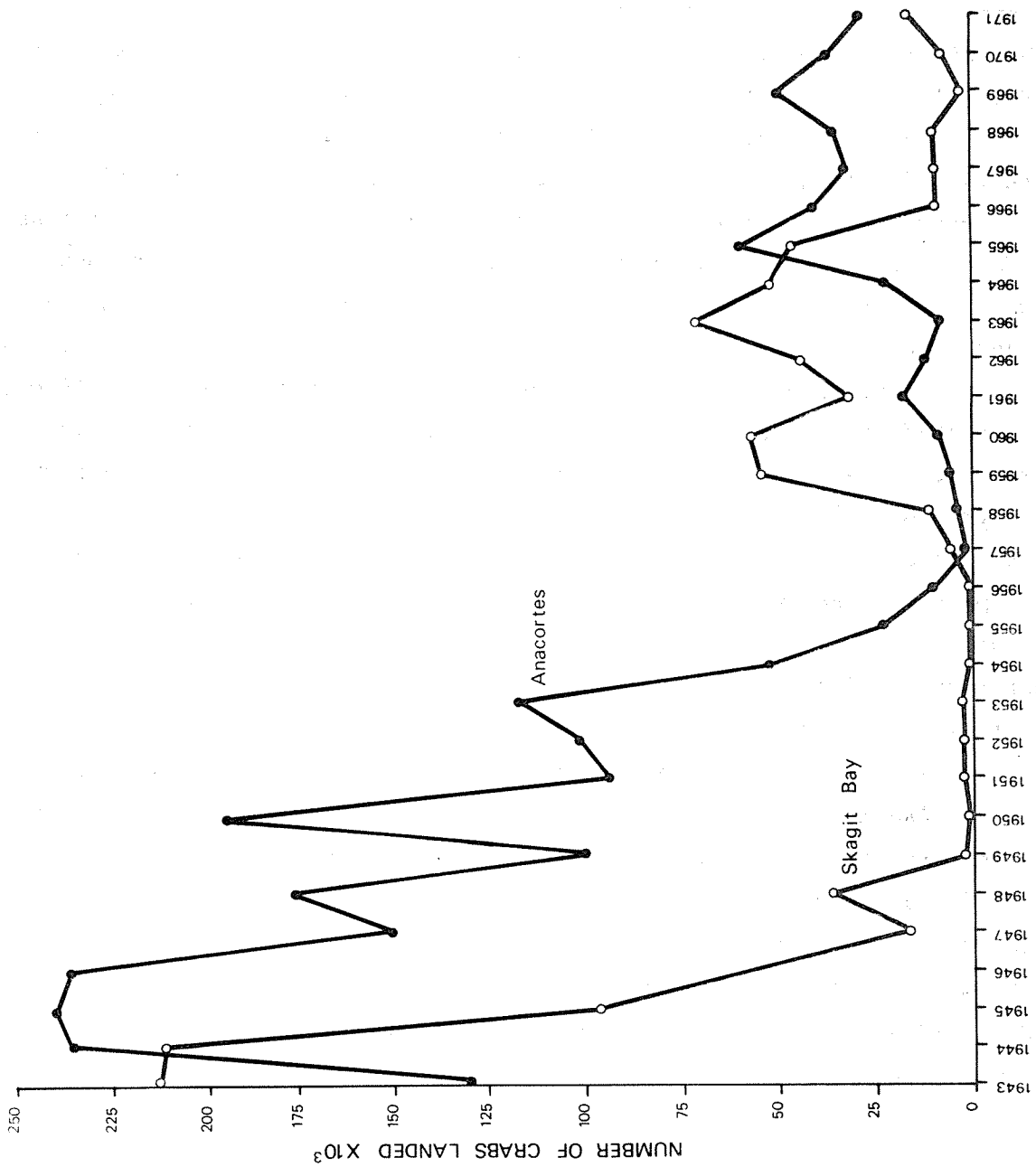


Fig. 8.2-1. Annual landings of *C. magister* from Skagit Bay and Anacortes areas for the period of 1943-1971. 1943-1964 catch statistics are taken from Anon., 1965. Remaining catch statistics were provided by Ward, 1973 (personal communication).

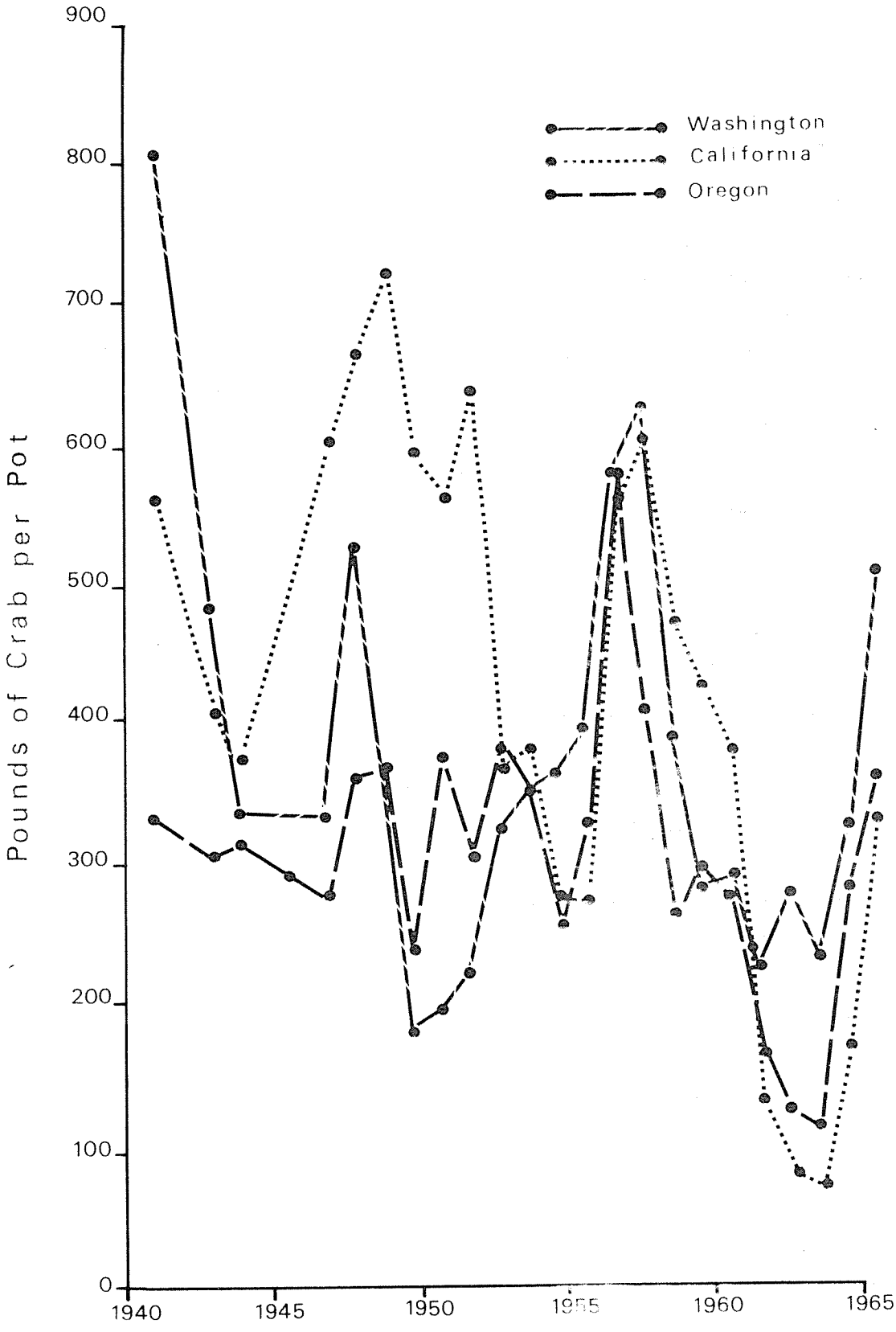


Fig. 8.2-2. Annual landings converted to pounds per pot per day in the Washington, Oregon, and California coastal fisheries from 1940-1965. Pounds of crab per pot were calculated from statistics found in Anon., 1966.

8.2.2 Materials and Methods

8.2.2.1 General

An initial survey of the distribution of crab pots in the Similk Bay and Kiket Island vicinity was made by boat. It was observed that the fishing effort was concentrated within 100 yards (91.4 m) of the shoreline of the study area. This distribution of local fishing effort is primarily a practical one. Any pots fished in the center of the Bay would be lost to boat traffic because tug boats with large tows commonly use Similk Bay as a holding basin while they await the proper tide for passage through Deception Pass. In addition, much of the recreational effort is conducted from small rowboats. At least one commercial fisherman interviewed fished an unbouyed string of 40-50 pots located in the center of the bay.

8.2.2.2 Test Crab Fishing

In order to collect baseline data on catch per unit of effort we fished crab traps continuously from 1970-1972 at eight locations in the vicinity of Kiket Island (Fig. 8.2-3). The traps were evenly distributed within the 100-yard (91.4 m) zone of local crab pot concentration. The crab traps, standard commercial pots weighing approximately 100 lb (45.4 kg), were fished in pairs. The second pot was placed approximately 100-200 ft (91.4-182.8 m) offshore of the inshore pot of the pair. During the summer of 1970, ten crab pots were fished in close circular and rectangular patterns on the north and south side of Kiket Island as shown in Fig. 8.2-3. The patterns were designed as a measured part of the recovery effort in a tagging-and-recapture study to measure the movements of crabs in an area tightly surrounded by crab traps. Recoveries were so few that the effort was terminated in September and the pots were relocated at the eight locations described above. The data collected on CPUE from this experiment are included in the analysis of the results of fishing at the eight locations.

Fishing was conducted at depths ranging from 18 ft (5.5 m) to 32 ft (9.7 m) (MSL). The average depth of all crab pots fished was 25 ft (9.7 m) (MSL). A metered block on the winch used to pull the crab pots was used to determine the depth fished. Preliminary test fishing had shown no significant

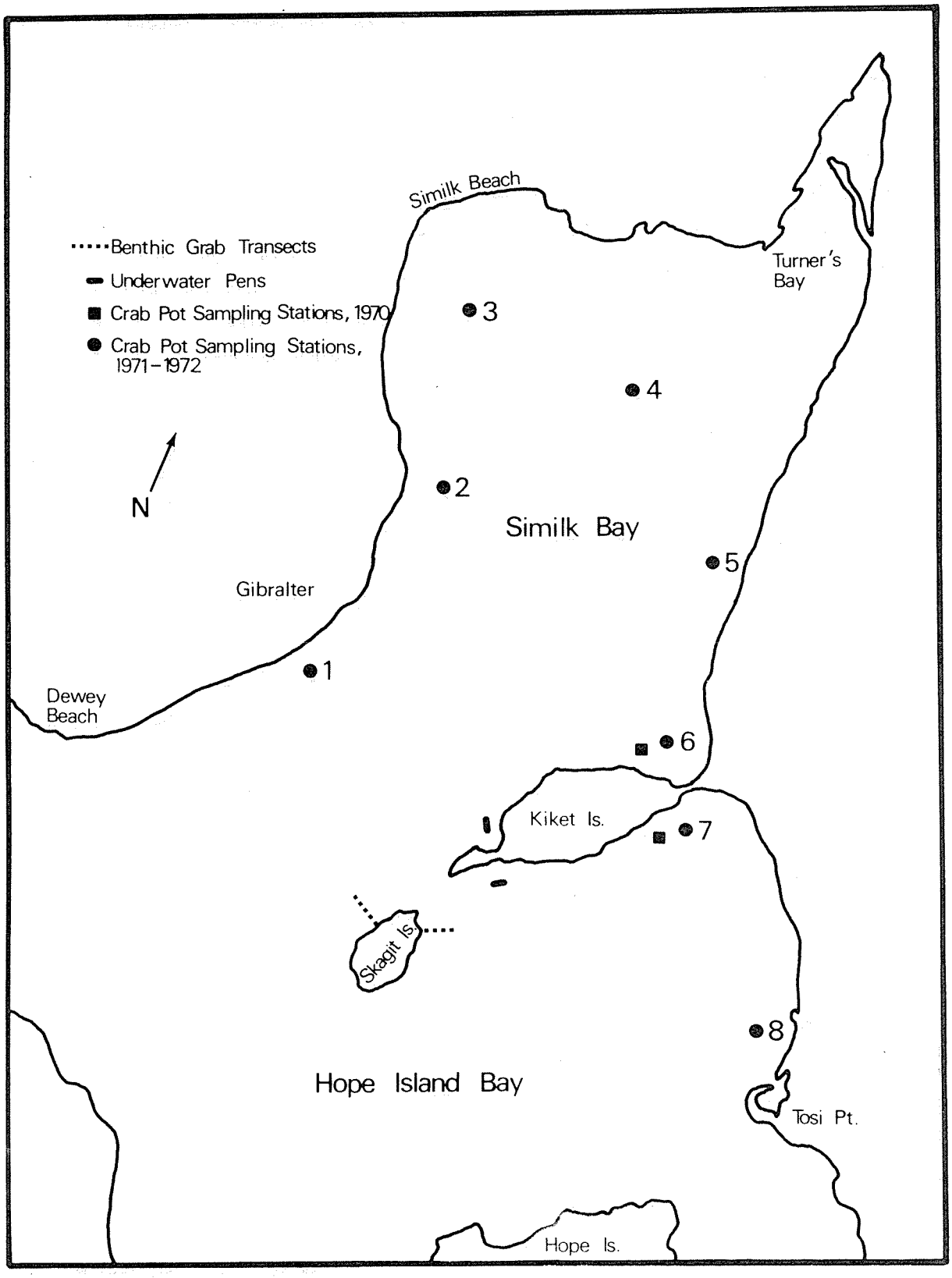


Fig. 8.2-3. Map of the study area showing the location and designation of crab pot sampling stations for 1970 and 1971-1972, underwater pen experiments, and benthic grab transects. Two crab pots were fished at each of the eight stations.

difference at the 95 per cent confidence interval between the mean CPUE for baited or unbaited pots; therefore, traps were not baited in order to eliminate the variance in the CPUE due to different baits. Pots were lifted and reset every 3 days during a 6-day sampling period at midmonth. This schedule produced catch data for a 24-day period between each monthly sampling and catch data for two 3-day periods each month. On a number of occasions weather or equipment malfunction caused breaks in this routine.

8.2.2.3 Crab Tagging

The number of crabs caught was recorded by date and location. The width of each crab was measured at the widest point of the carapace exclusive of the tenth anterolateral teeth and recorded. Sex and condition were also noted. A portion of the catch during 1971 was retained for use in laboratory experiments, but the majority was tagged and released in the area of capture.

From June 1970 to March 1971 Peterson disc and hydrostatic tags were secured with a stainless steel pin inserted through a hole drilled in the carapace with a 1/16-inch (0.16 cm) power drill. The crab was held in the laboratory in running sea water for at least 24 hr and released in the location of capture.

Beginning in April 1971 Floy anchor tags were used in place of Peterson disc tags. Each tag carried a 2-inch (5.1 cm) length of yellow vinyl tubing (FD-67) inscribed with the legend "REWARD U OF W FRI 0000." The tag was implanted with an unmodified Dennison tagging gun (FD-67) through the epimeral line approximately 3/4 of an inch (1.9 cm) from the most posterior margin, with the anchor shaft inserted downward into the most posterior leg muscles. A $1.00 reward was paid to the fisherman for return of each tag. An article with a photograph of a tagged crab was run in the Anacortes, Mount Vernon, LaConner, and Everett newspapers, describing the study, its purpose, and the procedure for identifying and returning recovered tags.

During the summer of 1971 a number of crabs were tagged and returned to the crab pots in which they had been caught and loss of tags and rate of escape were measured over periods of up to 30 days from successive lifts of the pots. The rate of escape was used in connection with other information to standardize all data on CPUE to a 3-day fishing period.

Beginning in the spring of 1971 a catch data form was sent with each reward check to fishermen requesting the following information: (1) date of capture, (2) number of days the pot was fished, (3) number of each tag caught, (4) number of untagged crabs caught with the tagged crab, (5) location of crab pots on an accompanying map. This procedure was continued until the end of the study.

8.2.2.4 Recreational and Commercial Fishermen Survey

On December 5, 1972 a survey questionnaire designed to obtain information on the seasonality of fishing effort was mailed to all persons who had returned tags. The recipient was asked to estimate the number of pots he fished, the number of days he fished the pots, and the number of legal-size crabs he caught during each month of 1971. He was also asked to indicate his age, his residency, his estimate of the value and personal use of the crab resource, the value of his fishing gear, and fishing methods.

8.2.2.5 SCUBA Surveys

8.2.2.5.1 Sled Survey of Crab Densities. An additional measure of crab abundance was provided by surveys with the use of SCUBA during the summer of 1971. One or two divers were towed by a power skiff over a 10-min course. The diver rode a simple wooden sled in the shape of a "T," with the stern provided with a smaller "T" made of PVC pipe and attached perpendicularly to the surface of the sled. The diver held this small handle between the legs for support. The sleds were made of 1/2-inch (1.27 cm) marine plywood and coated with white fiberglass epoxy. The diver counted all crabs seen in the tow over a lateral path approximately 3.3 ft (1.0 m) wide. Five series of 10-min tows were conducted at each of the crab pot stations shown in Fig. 8.2-3.

8.2.2.5.2 Crab Track Observations. Information was collected on the direction of crab movements by divers using SCUBA at each of the eight crab pot study sites. When the diver reached the submerged pot, he swam due north for 20 or 30 ft (6.1 or 9.1 m), then due west for the same distance from the crab pot. After a number of observations of the

pattern of tracks left by crabs released on mud bottom, it was possible to read the crabs' direction of movement. All identifiable crab tracks were read by the use of an underwater compass. These readings, in degrees, were averaged for each location and compared with the migration patterns developed from tag release-and-recovery information.

8.2.3 Results

8.2.3.1 Results of Fishermen Survey

The following description of the Similk Bay-Kiket Island crab fishery was derived from replies to the December 1972 survey questionnaire. Thirty-six out of fifty, or 72 per cent of the questionnaires were returned. All of those who did not respond had returned only one tag during the 3-yr study and probably played a minor role in the fishery.

The responding fishermen ranged in age from 15 to 74 years with an average of 46. The variety of occupations was great, including student, medical doctor, stock broker, mechanic, and retiree, to name a few. Eighty-seven per cent were year-round residents of the Kiket Island area and had lived there for an average of 11 years, and the remainder were weekend or summer vacationers. Crab fishing experience ranged from 1 to 47 years, but averaged 8.5 years. The majority (80%) were recreational fishermen. The fishermen estimated that they took a total of 2,180 crabs a year, or 34 per cent of the annual commercial and recreational catch reported in the questionnaires (6,282). Thus two-thirds of the catch was taken by the commercial fishery.

Recreational fishermen consumed an average of 10 crabs per month and ate crab an average of 2.8 times a month. Each fisherman gave away an average of 4-1/2 crabs each month. They indicated that an average annual license fee of $2.80 would be acceptable to insure their present fishing success. Those persons able to respond to the question asking for an estimate of the amount they would charge someone to fish for their crabs were willing to sell their crab rights for an average of $8.00 a year. The market retail value of their estimated total catch would be approximately $4,000.

The average recreational fishermen had $35 invested in crab pots and another $710 in support gear. Only 33 per cent of those fishermen who responded were satisfied with the number of crabs they caught each month. The remaining two-thirds indicated they would be satisfied with an average catch of 20 crabs per month.

The annual value of the commercial crab fishermen's catch from Similk Bay ranged from $700 to $2,000, averaged $1,350 per fishermam, and represented between 7 and 20 per cent of their total annual income. All of the commercial fishermen who had fished in other areas rated Similk Bay as a poorer fishing area. Their average investment was $725 in crab pots and $4,000 in boats and other equipment. The wholesale value of their combined landings was approximately $3,500.

All fishermen who responded to the questionnaire baited their pots, commonly with clam meats and fish. The most common baits used were horseneck clams (*Tresus nuttalli*) and herring. Other baits mentioned included dogfish, salmon parts, cockles, cod, sole, and fish-flavor cat food. The pots were fished in depths ranging from 11 to 40 ft (3.3 to 12.2 m) and at an average depth of 23.4 ft (7.1 m). They were lifted on the average every 4 days. The typical fisherman fished 116 days a year (*see* Fig. 8.2-4) with 1-2 pots if he was a recreational fisherman and 40 pots if he was a commercial fisherman. The commercial fishing effort was the greatest during the winter months. The maximum recreational fishing effort was nearly the exact opposite time of the year during the summer months. The overall CPUE calculated from the fishermen's estimates of catch and days fished was 0.933 ($\pm$0.15) crabs per pot per day. The distribution of the average annual fishing effort and CPUE among fishermen responding to the questionnaire survey is shown in Fig. 8.2-5 and Fig. 8.2-6, respectively.

8.2.3.2 Crab Catch from Research Fishing

8.2.3.2.1 Catch Adjustment. The data on CPUE from all study pots were analyzed for a relationship to the number of days the pots were fished. The results showed a highly significant inverse linear relationship when fit by the power function of ln CPUE regressed against ln days fished. A "t-test" between the slope of this relationship and one calculated by Cleaver (1949) for the coastal crab fishery

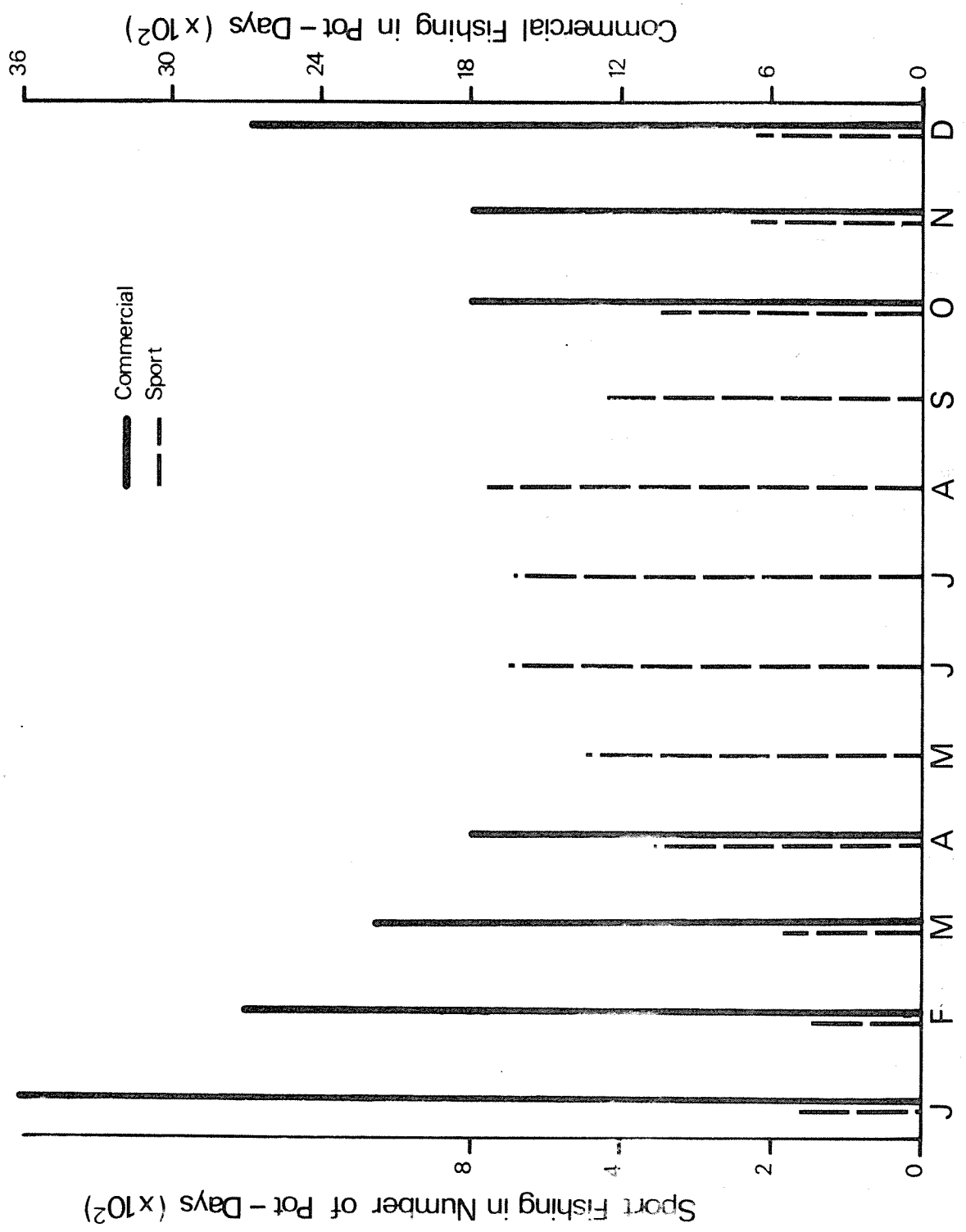


Fig. 8.2-4. The monthly fishing effort in pot-days fished of recreational and commercial fishermen as reported in a questionnaire survey, 1972.

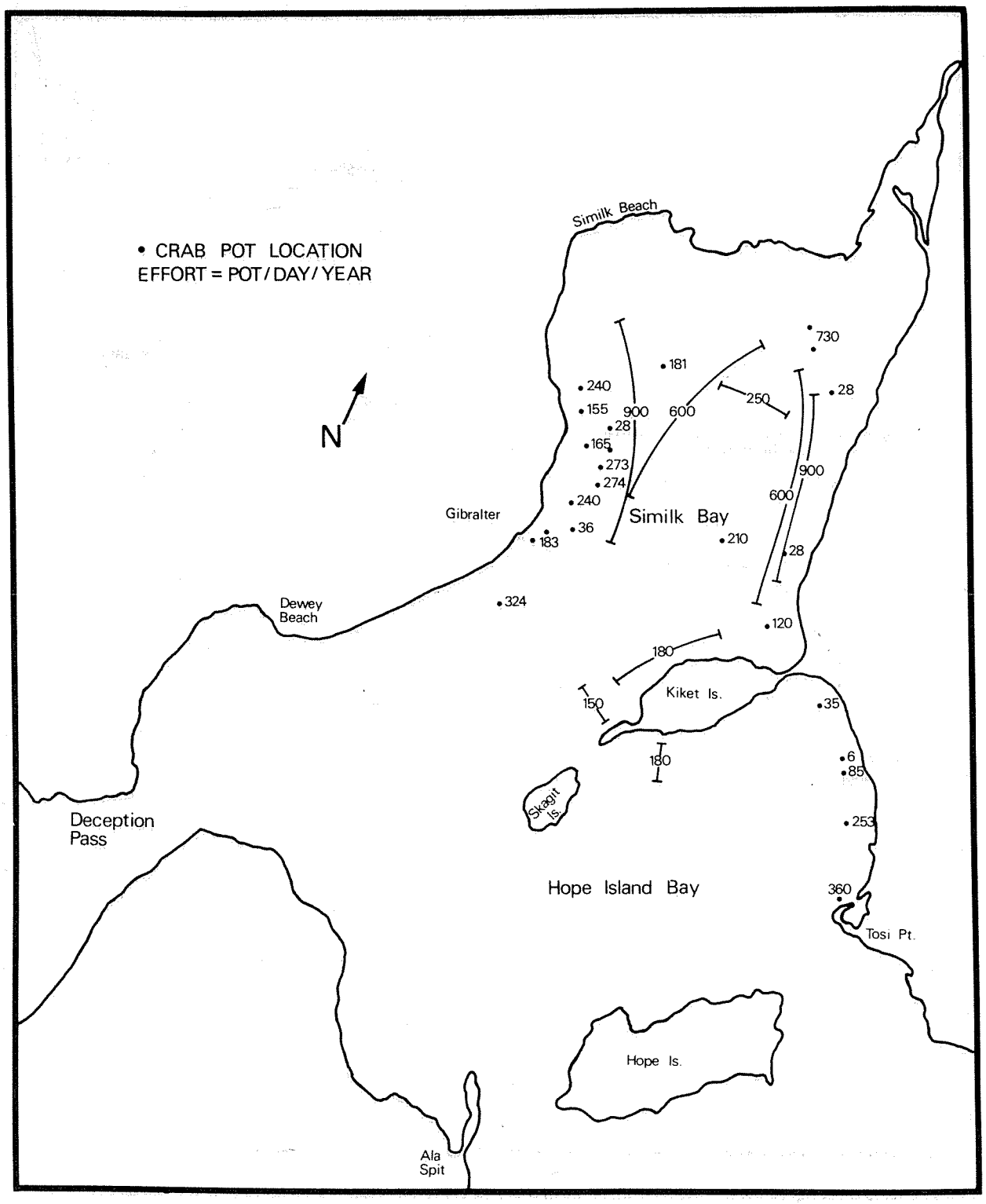


Fig. 8.2-5. The distribution of fishing effort in total annual pot days as reported by local fishermen in a questionnaire survey, 1972. Lines indicate location of pots fished as a group by one fisherman.

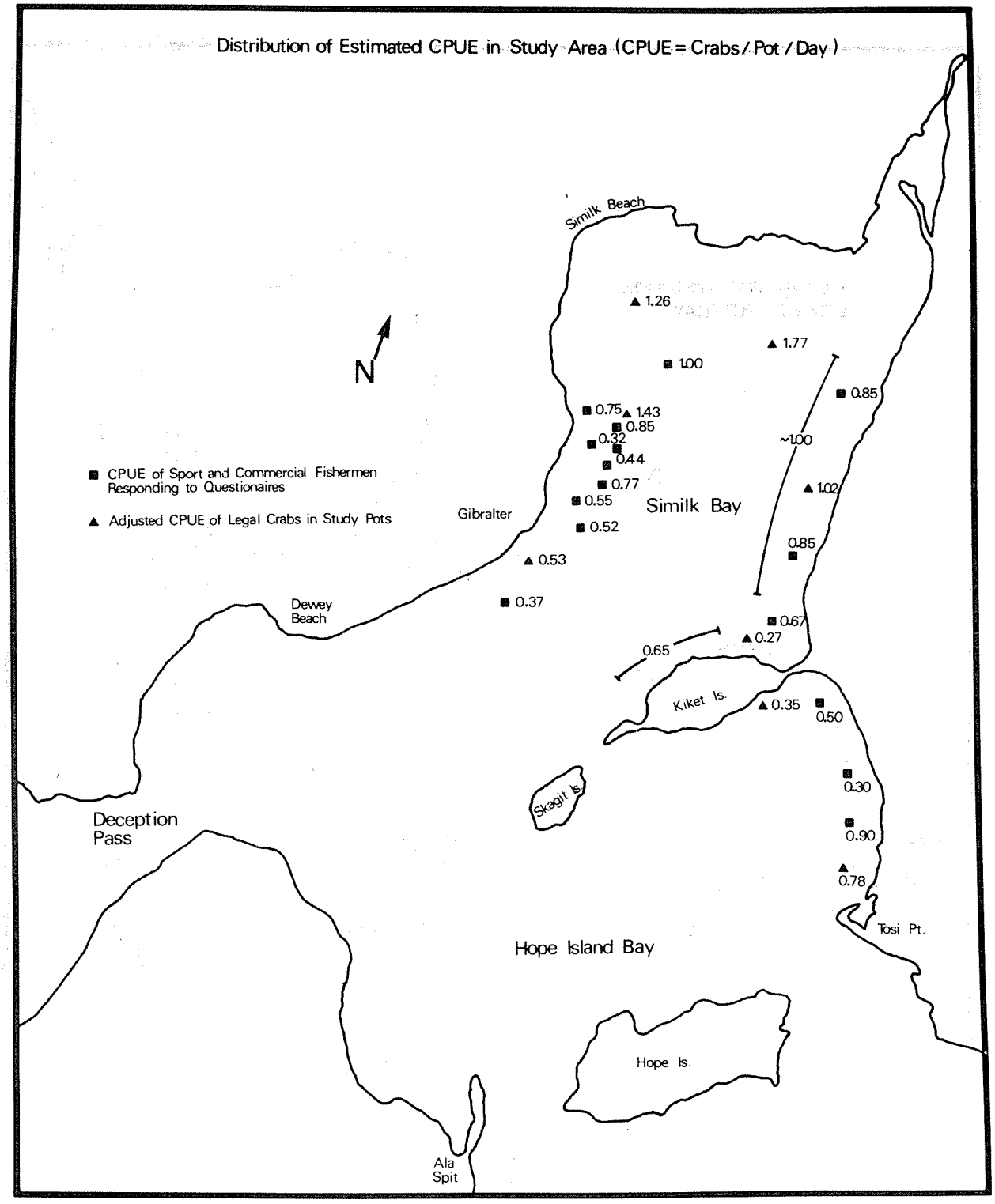


Fig. 8.2-6. A map of the study area showing the distribution of average annual catch per unit effort in crabs per pot per day as reported by local crab fishermen in a 1972 questionnaire survey. Lines indicate the location of pots fished as a group by one fisherman.

showed no significant difference. Experiments on the escape of tagged crabs from the study pots were analyzed in a similar manner by the use of the same power function model. A highly significant inverse relationship was found when the ln of the number of tags in the pot at time, $t_n \ldots t_{n+1}$, was regressed against the ln of time, t. The following equations are the results of these two analyses:

CPUE vs days fished $\quad \ln Y = 0.244 - 0.998$

crabs escaped vs days in pot $\ln Y = 0.223 - 0.921 \ln X$

The equations are solved graphically in Fig. 8.2-7. The slopes or intercepts of the two equations were found not to differ significantly at the 99 per cent conficence level by a "student's t-test."

8.2.3.2.2 Length Frequency of Catch. The mean length of male crabs caught in the overall sampling period was 6.27 inches (15.93 cm). The mean length of female crabs was 4.68 inches (11.9 cm). The length grequency distribution of the catches are shown in Fig. 8.2-8. The low number of crabs of less than 5.12 inches (13.0 cm) is the result of gear selectivity. It was thought that the escape port provided on each pot accounted for the catch size distribution. However, in traps where these ports were wired shut, there was no significant increase in the number of undersized crabs caught. The Kiket Island crab population is dominated by a legal and nearly legal size age class. There does not appear to be the necessary number of immature crabs in the area to support the size of the adult population.

8.2.3.2.3 Occurrence of Ovigerous Crabs. Female crabs were seldom taken in the catch, supposedly because the open ports on the crab pots permit crabs less than 6.06 inches (15.4 cm) wide to escape. However, no increase was noted in the number of females caught after the escape ports were wired shut during a later portion of the study. The majority of females taken were trapped in the winter and spring months. Seventy-three per cent were ovigerous. The monthly distribution of their occurrence is illustrated in Fig. 10-5 (section 10.0). They began appearing in

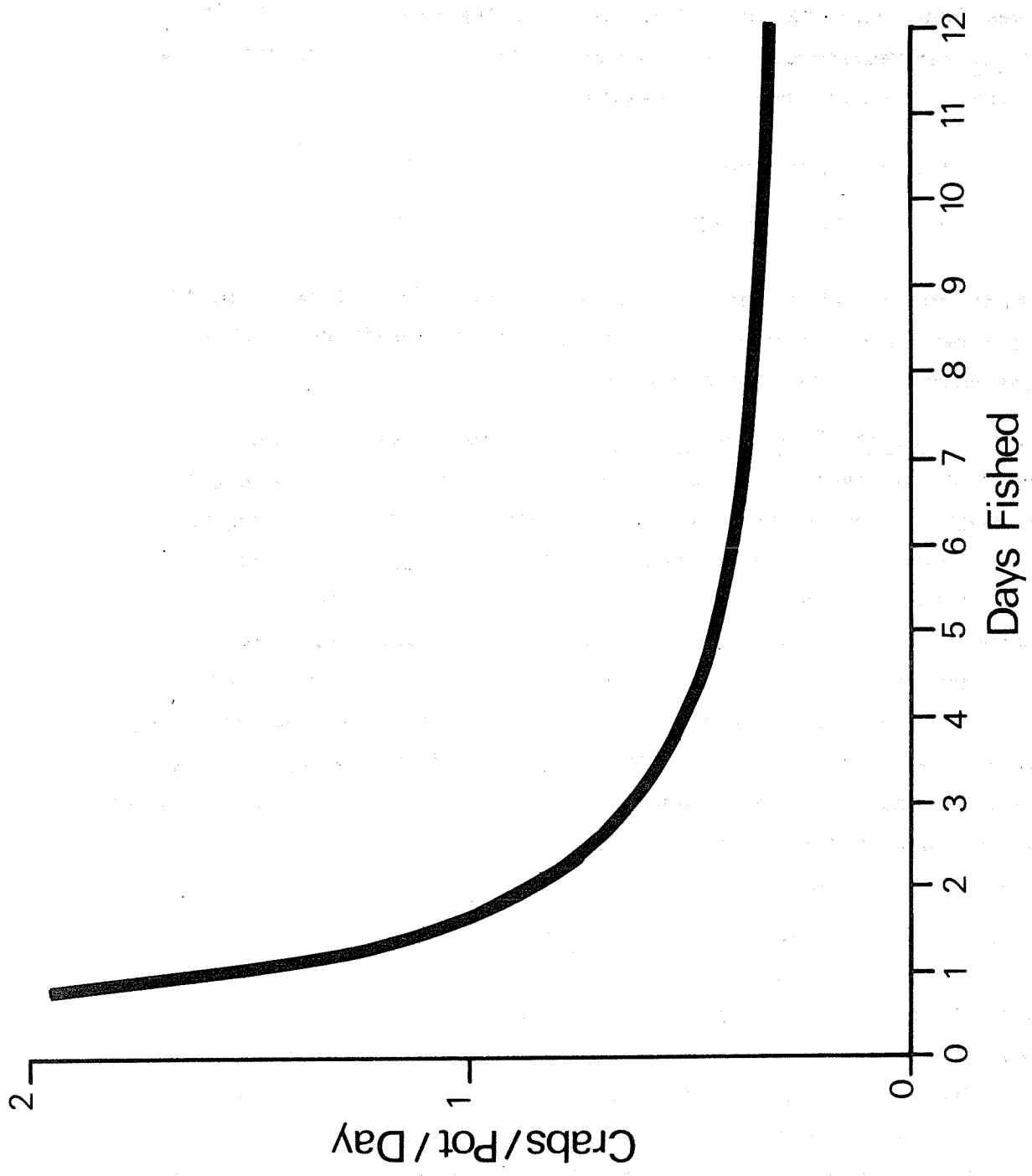


Fig. 8.2-7. A curve fit by least squares to the relationship between days pots were fished and CPUE in crabs per pot per day. This curve also describes the escape rate of tagged crabs from crab pots.

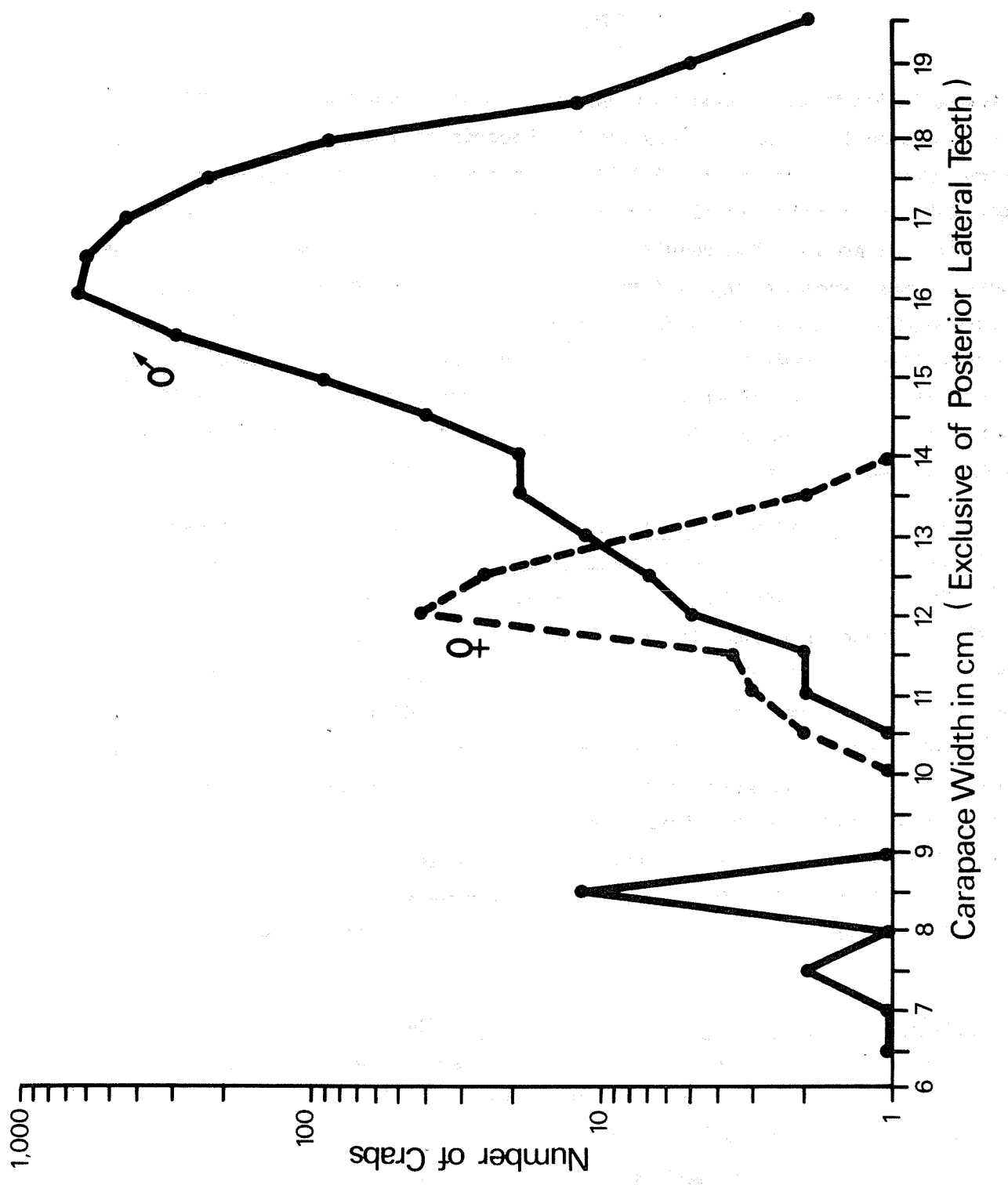


Fig. 8.2-8. A frequency diagram of the length of male and female *C. magister* caught at all sampling stations during the 1970-1972 sampling period. Widths are exclusive of the 10th anterolateral teeth.

the traps in November 1970 and in January 1972 and occurred in maximum abundance in January 1971 and February 1972. Records on the degree of hatching were incomplete for the spring of 1971. Observations of the egg masses during 1972 showed that hatching had apparently begun in mid-March and was very evident in April. The results shown in Fig. 10-5 suggest that there was a delay in appearance of eggs and therefore possibly in onset of egg deposition during 1971 compared to 1972. Included in Fig. 10-5 is a plot of the catch of ovigerous females at each of the eight sampling locations. During both the 1970-1971 and 1971-1972 periods, stations 2 and 7 (respectively the west and east shores of Similk Bay) had significantly greater catches of ovigerous females than the other stations and station 3 yielded none.

8.2.3.2.4 Occurrence of Softshell Crabs. The catch distributions of crabs with soft shell and new shell (Fig. 8.2-9) by month in both sampling years, 1971 and 1972, indicate three periods of moulting. Peaks of abundance in crabs with soft shell occurred in January, May, and August of 1971 and 1972. Crabs with new shell began to appear in the catch one to two months after these peaks. The distributions of soft-shelled crabs in the catch by station for 1971 and 1972 (also in Fig. 8.2-9) indicate a significantly greater catch of soft-shelled crabs at stations 4 and 8 (respectively, north Similk Bay and Tosi Point) than at the other stations in both years. A rank correlation comparison of the occurrence by station of soft-shelled crabs and ovigerous females showed a negative correlation for both years which was significant at the 95 per cent confidence level.

8.2.3.2.5 Catch -per-unit Effort by Season. The mean catch-per-unit effort (CPUE) of the eight sampling stations is shown for each sampling date in Fig. 8.2-10. A large percentage of the crab pots were stolen and lost to tug boats and gillnet fishermen; therefore the actual number of pots fished for the means at each sampling date varied from a low of 10 pots to a maximum of 16 pots. Included in the Fig. 8.2-10 are unadjusted CPUE, adjusted CPUE, and adjusted CPUE of legal-size crabs. These curves are accompanied by the continuously recorded laboratory water temperatures. These

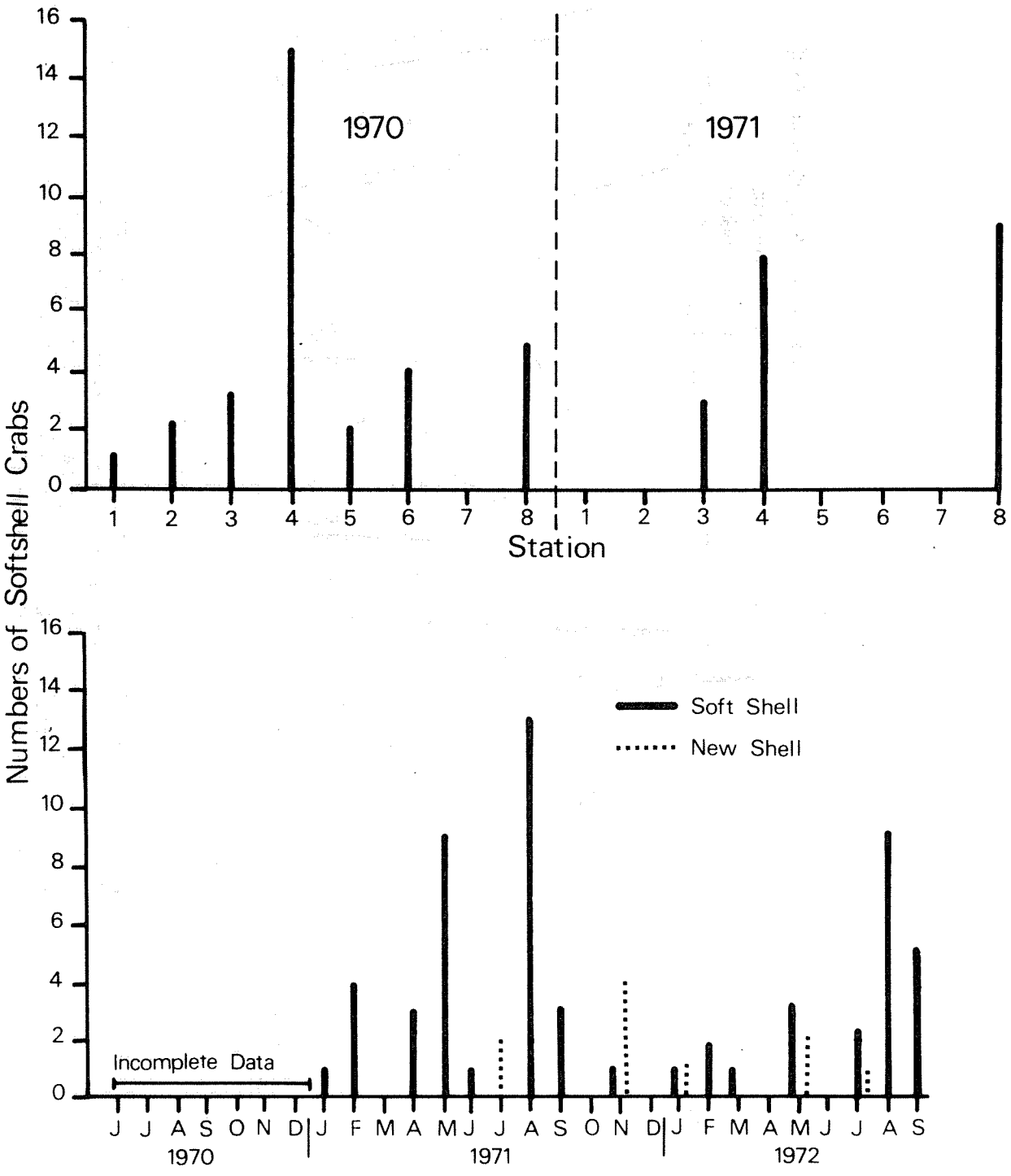


Fig. 8.2-9. A frequency diagram by month and station showing the number of softshell and new shell *C. magister* caught during the 1970-1972 sampling period.

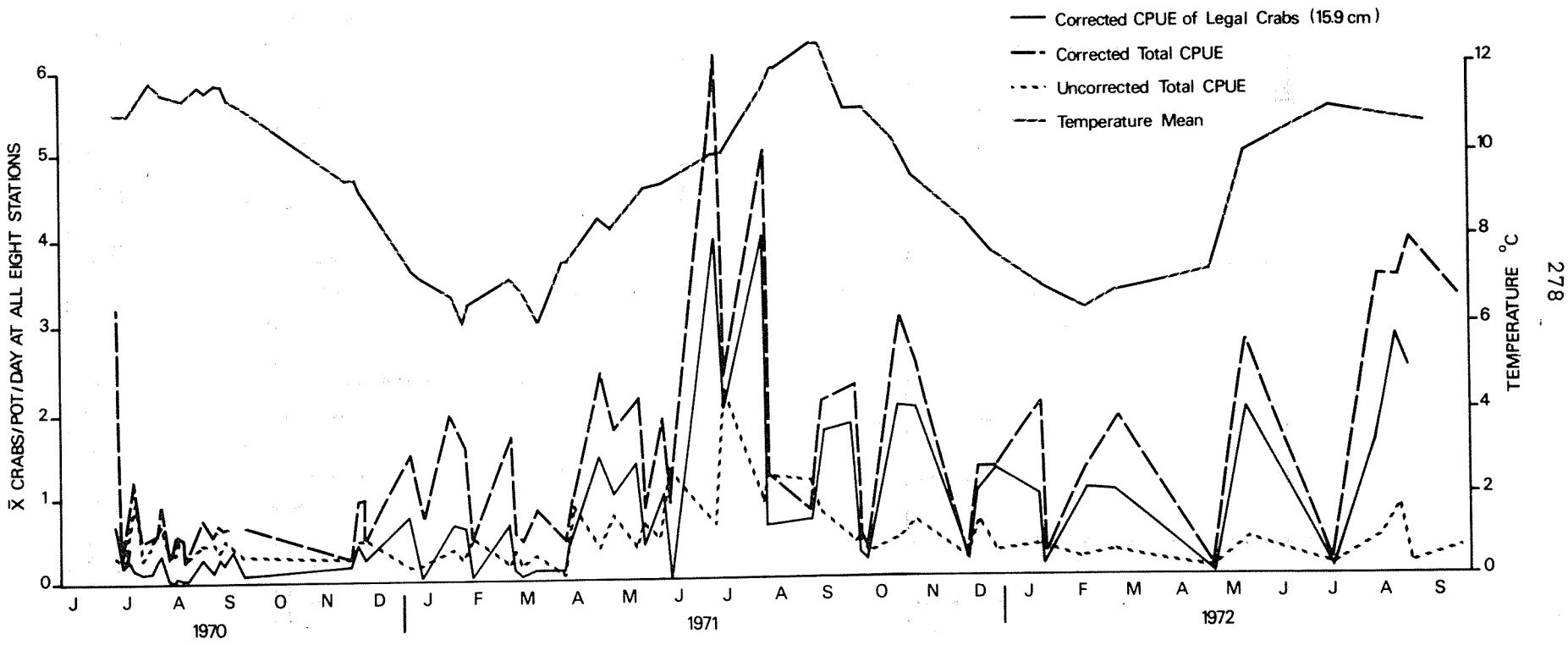


Fig. 8.2-10. The mean adjusted and adjusted legal size catch per unit effort of crabs per pot per day for all sampling stations on each sampling occasion during the period of 1970-1971. Included are continuously recorded laboratory water temperatures during the same time interval.

temperatures were of water drawn from a depth of approximately 10 ft (3.05 m) (MLLW) off the north shore of the Island and are representative of the water temperatures at the depths the pots were fished. The relationship between the temperatures and CPUE seen in Fig. 8.2-10 proved to be significant at the 95 per cent confidence level in a linear regression analysis. A similar test of the relationship between CPUE and salinity failed to account for any significant amount of variance in the CPUE data.

8.2.3.2.6 SCUBA Surveys. The results from the underwater sled surveys are shown in Table 8.2-1. The numbers of crabs observed in each survey were converted to densities of crabs/m^2 by division of the number observed in the transect by the estimated area covered in a 10-min tow. The area was estimated by multiplication of the length of tow as judged from boat speed and landmarks by the 3.3 ft (1.0 m) width of the field of observation. The calculated densities from the transects were converted to a mean density of crabs in Similk Bay. Multiplying by the total bottom area of Similk Bay gives an estimate of the standing crop of crabs.

This estimate has many errors due to visibility and avoidance behavior of the crabs. Used as an index rather than absolute level of crab abundance, it should be useful for comparative purposes. The results of the sled surveys indicated strong seasonal differences in the number of crabs observed. Station 1 had the lowest density followed by stations 5 and 8. These results compare favorably with the differences seen in the CPUE by sampling station.

8.2.3.2.7 Catch-per-unit Effort by Location and Comparison to Fishermen's Catch. The mean CPUE for the entire study was 0.489 crab/pot/day (c/p/d) unadjusted, or 1.438 c/p/d adjusted to a 3-day fishing period. A "students t-test" of the mean offshore CPUE, 1.445 c/p/d, and mean onshore CPUE, 1.426 c/p/d, showed that the two populations were significantly different at the 99 per cent confidence level. The adjusted study-pot CPUE is compared to the fishermens' CPUE in Fig. 8.2-11.

Table 8.2-1. The number of crabs observed by a SCUBA diver during a 10-min ride on an underwater sled. Counts are of crabs observed in a transect 1 m x 440 m

	Crab pot stations							
Date	1	2	3	4	5	6	7	8
5/23/71	1	1	1	2	0	1	0	2
7/17/71	1	3	2	2	1	0	1	0
9/24/71	0	0	1	3	1	1	2	1
11/17/71	0	0	0	1	0	0	0	0
2/22/72	0	0	0	0	1	1	0	1
TOTAL	2	4	4	8	3	3	3	4
MEAN	0.40	0.80	0.80	1.60	0.60	0.60	0.60	0.80
SD	0.59	1.30	0.93	1.11	0.54	0.54	0.60	0.80

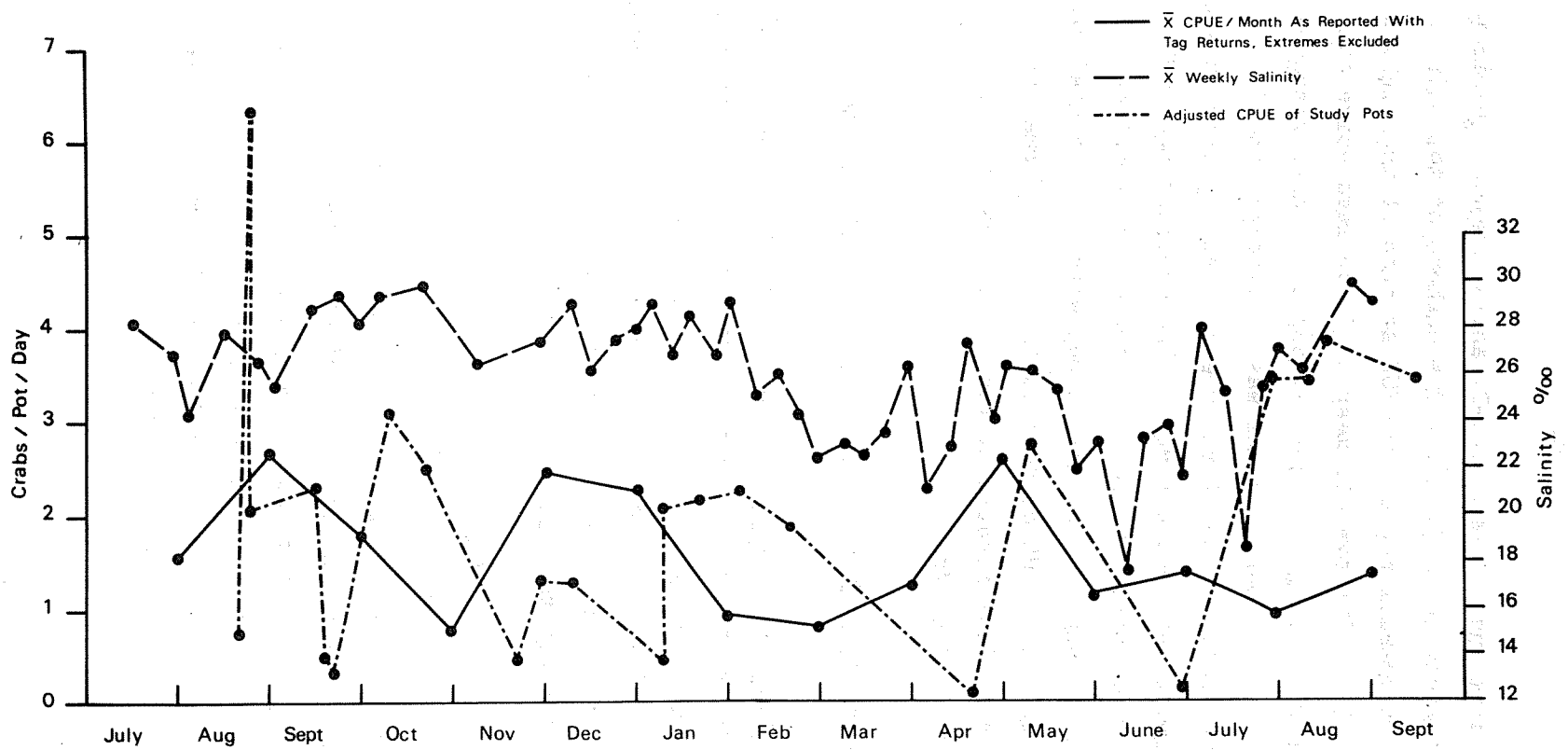


Fig. 8.2-11. The catch per unit effort of *C. magister* in crabs per pot per day calculated from catch information accompanying fishermen's tag returns. Included are the adjusted CPUE means for the study sampling stations and salinity means recorded in the laboratory.

The CPUE at stations 1-A and B, 3-B, and 8-A were significantly lower than all other stations (A = offshore, B = onshore of the pair of pots at each station). The overall means for CPUE at each of the eight stations are listed in Table 8.2-2. The overall mean CPUE for legal-size crabs was 0.798 c/p/d. The CPUE among recreational and commercial fishermen based on tag-return forms and on questionnaires was 1.012 c/p/d and 0.758 c/p/d, respectively. The distribution of their effort and success in shown in Fig. 8.2-5 and Fig. 8.2-6, respectively. The combined mean CPUE is 0.885 c/p/d. The catch per unit effort of the local fishermen as reported with their tag returns is plotted throughout the year along with the adjusted study pot CPUE in Fig. 8.2-11. Only the CPUE calculated from the information accompanying tag returns differed significantly at the 95 per cent confidence level from the study mean of 0.798 c/p/d.

8.2.3.3 Population Estimates from Mark-and-Recapture Study

8.2.3.3.1 Statistical Method. Tag returns were analyzed through the method as detailed by Jolly (1963). Analysis was conducted of mark-and-recapture information over three time intervals, as shown in Table 8.2-3. According to the continuous mark-and-recapture censuses, the number of marked crabs that survived from the previous marking period may be estimated through the equation:

$$M'_0 = M_1 \frac{m_{02}}{m_{12}+1}, \qquad (1)$$

Where M'_0 = number of marks surviving from previous marking,

M_1 = number of marks placed after the previous interval,

m_{02} = number of marks recaptured from the first marking in the second interval, and

m_{12} = number of marks recaptured from the second marking in the second interval.

The survival, S is then estimated as

$$S_0 = \frac{M'_0}{M_0} \qquad (2)$$

Table 8.2-2. The mean adjusted, adjusted legal size, and unadjusted catch per unit effort in crabs per pot per day at the eight sampling stations for the period of June 1970 to September 1972

	Crab sampling stations								
	1	2	3	4	5	6	7	8	Overall
Mean total adjusted CPUE	0.836	2.010	1.930	2.617	1.902	0.810	0.933	1.463	1.438
Standard deviation	1.374	2.425	2.695	3.266	2.231	0.946	1.008	1.869	2.051
Sample size	39	53	59	59	55	149	92	52	560
Mean total adjusted CPUE of legal size crabs (<15.8 cm)	0.532	1.427	1.262	1.767	1.016	0.274	0.349	0.784	0.798
Standard deviation	1.071	2.083	1.860	2.686	1.442	0.564	0.541	1.464	1.543
Sample size	39	53	59	59	55	149	92	52	560
Mean total unadjusted CPUE	0.242	0.606	0.570	0.698	0.507	0.459	0.419	0.417	0.577
Standard deviation	0.422	0.653	0.951	0.768	0.576	0.502	0.458	0.456	0.345
Sample size	39	53	59	59	55	149	92	52	560

Table 8.2-3. A summary of the number of tagged crabs released by tagging interval and the number recovered from each tagging interval by month. Included are the total number of crabs released and recovered. Percentage of recovery = 17.06

Tagged crabs released		Number and date of tagged crabs recovered																														
		1970							1971												1972											
Date	Number	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	Total
1970																																	
6	17		1	0																													1
7	145			3	5	1	2																										11
8	72																																
9	19					1	1																										2
10	0																																
11	106							6	1	1		4			1	1																	14
12	47								2	1		2	3	2	1	3										1							15
1971																																	
1	39																																
2	80										3		1	1	1		1																7
3	43												1	1	1	1			2			1											7
4	154												4	3	2	2	1						1	2									15
5	212													14	4	7	3	1	2		2	3	1		2	1	1	1		1			43
6	276														11	15	4	2	5	6	4	1	1	1	3	2							55
7	8																																
8	158																6	4	3	4	2	2	1	1	2	5		1					31
9	98																	2	3	5	9	2		1		4	1						27
10	99																		6	2	8	2	3	2	2	5	3		1		2		36
11	65																			2	4	2	2	3	4	2	1	1	1		2		24
12	0																																
1972																																	
1	110																					4	4	4	2		2	1	1	1	2		21
2	94																						1	2	1	3	3	1			1		12
3	0																																
4	53																								3	1							4
5	60																									2	2	2	2	1	2		11
6	51																										1	5	2		1		9
7	50																											2	3	1			6
8	0																																
9	0																																
Total	2,046																																349

The coefficient of total mortality, Z, which is the result of the natural mortality, M, and fishing, F, is estimated as follows:

$$Z = M + F_0 = -\ln \frac{M'_0}{M_0} \qquad (3)$$

where M = natural mortality, and

F_0 = the fishing mortality during time interval 0.

F_0 may be found as follows:

$$F_0 = \frac{m_{01}}{M_0 - M'_0} \ln \frac{M_0}{M'_0} \qquad (4)$$

M, natural mortality is then estimated by subtraction:

$$M = M + F_0 - F_0 \qquad (5)$$

Next, N, the total number in the population during the first interval, is estimated:

$$N_1 = \frac{M'_0 n_1}{m_{01}+1} = \frac{M_1 n_1 m_{02}}{(m_{01}+1)(m_{12}+1)} \qquad (6)$$

where n_1 = number in sample in period 1, and

m_{01} = the number of marks recovered in period 1 from the 0 marking occasion.

Similarly N_2 is estimated:

$$N_2 = \frac{M_2 n_{13}}{M_1 (m_{12}+1)(m_{23}+1)} \qquad (7)$$

The variance of S_0 and N_1 are estimated:

$$\text{Est var } S_0 \sim S_0^2 \left(\frac{1}{m_{02}} + \frac{1}{m_{12}}\right) \qquad (8)$$

$$\text{Est var } N_1 \sim N_1^2 \left(\frac{1}{m_{02}} + \frac{1}{m_{01}} + \frac{1}{m_{12}}\right) \qquad (9)$$

8.2.3.3.2 Survival and Fishing Mortality Rates. The survival and total mortality coefficients were calculated for the mark-and-recapture intervals from July 1970 to August 1972. The quantity "m_{01}" in Eq. 1 was taken as the sum of all tags returned in the intervals exclusive of m_{00} from the M_0 marking occasion.

The quantity "m_{12}" in Eq. 1 was taken as the total number of returns from the M_1 marking occasion. The survival and total mortality coefficients for all census intervals are shown in Fig. 8.2-12. The average monthly survival over the entire study period was estimated at 0.827, or 82.7 per cent (±20.5). The overall mean of the mortality coefficients calculated for each mark-recapture interval was 0.487. The calculated fishing mortality, F_1, for each mark-and-recapture interval is plotted with Z for the same interval in Fig. 8.2-13. The difference between the two lines represents the estimated natural mortality that occurred during the interval. The average of the fishing mortalities from each interval was 0.206, or about half of the total mortality averaged for the same intervals.

8.2.3.3.3 Estimated Crab Population Size. The calculation of N_i for each i^{th} interval produced a mean population estimate; $\hat{N}$, of the crabs in the Kiket Island area of 14,000 (± 5,500). In the same manner, the population of crabs in Similk Bay was estimated from the mark-and-recapture figures from the stations in the Bay(i.e., 1, 2, 3, 4, 5, and 6). The resulting estimate, N, was 10,500 (±2,800). The variance of the Similk Bay estimate was less than that for the combined Hope Island Bay and Similk Bay area, possibly because of the closed nature of the Similk Bay population. This conclusion agrees with the results of migration studies based on mark-and-recapture information, presented below.

8.2.3.4 Migrations

8.2.3.4.1 General. Of the 2,046 tags released during the period June 1970 to September 1971, 349 tags, or 17 per cent, were returned; and of these returned tags, 185 were accompanied by information of use in estimating the movements of the crabs after release. The commercial crab fishermen proved to be not as cooperative as the recreational fishermen in this regard. The recreational fishermen in Similk Bay generally fish their pot(s) in one spot, whereas commercial fishermen fish throughout the Bay. Moreover, they frequently move their pots and are too busy with their crabbing operations to keep field notes. On many occasions a large number of tags (10-15) were received

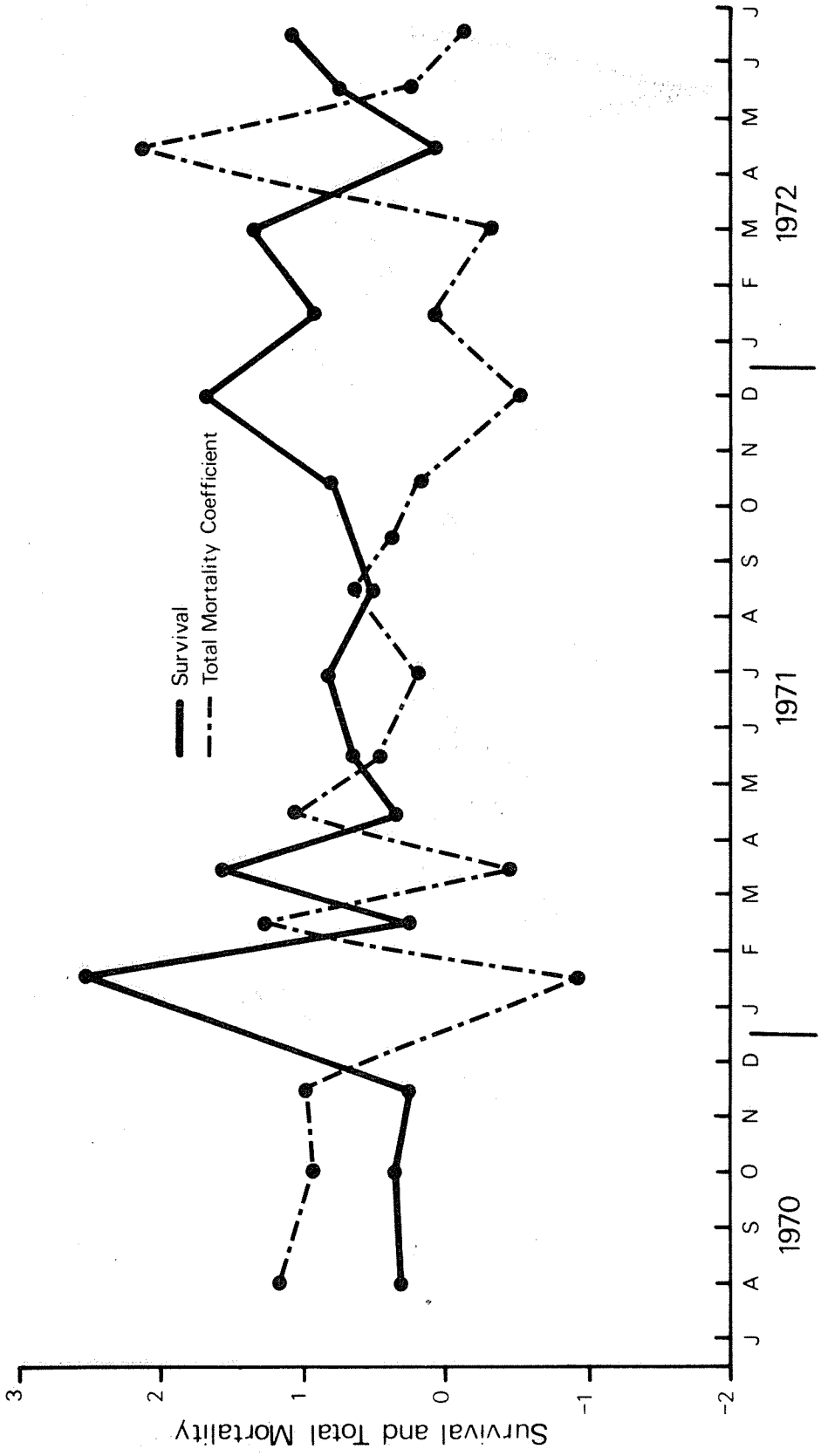


Fig. 8.2-12. The survival and total mortality rates of *C. magister* based on an analysis of tag return information according to Jolly (1963) for the sampling period of July 1970 to June 1972.

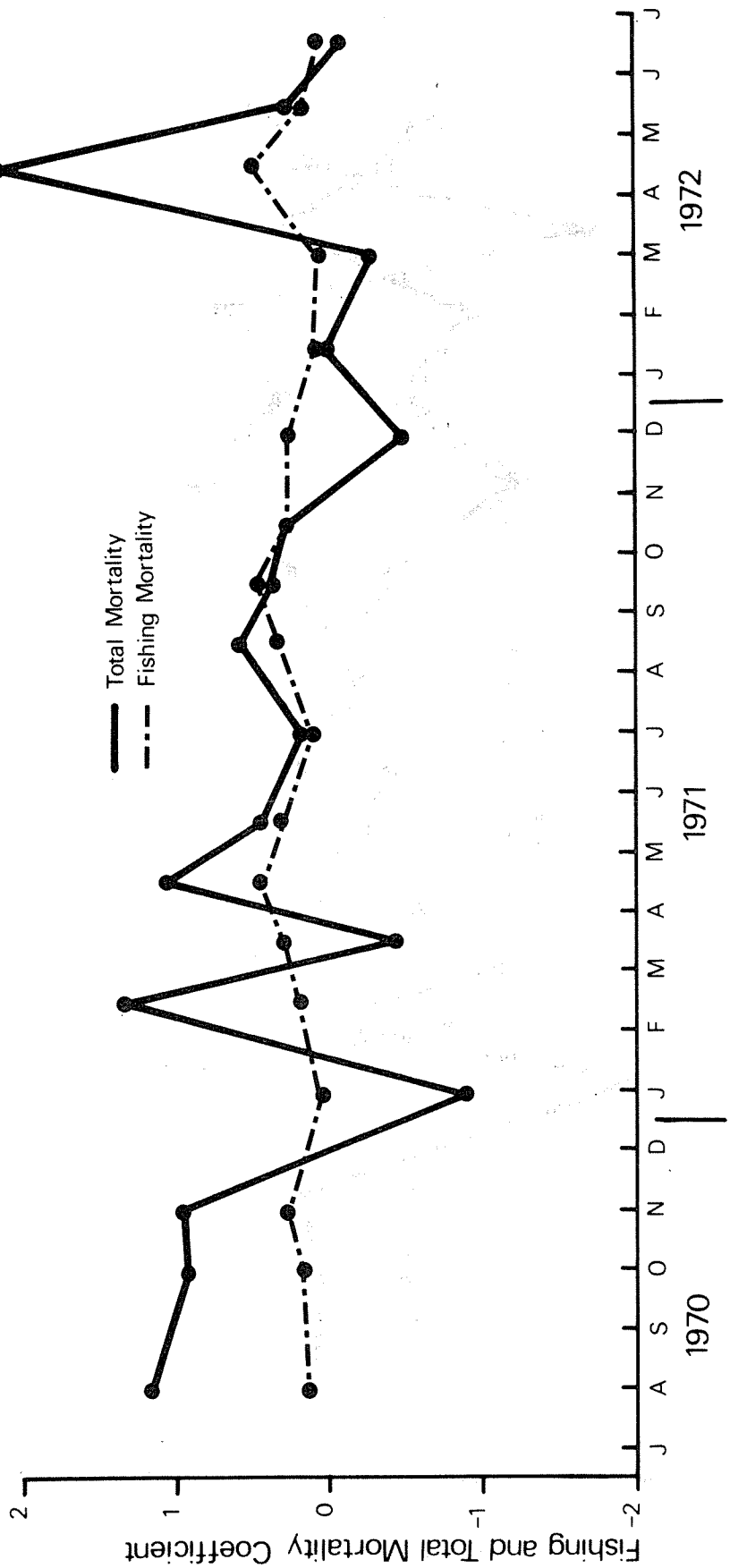


Fig. 8.2-13. The total mortality and fishing mortality rates of *C. magister* based on an analysis of tag return information according to Jolly (1963) for the sampling period of July 1970 to June 1972.

in a single envelope with the explanation that they were caught in Similk Bay at an undetermined time. In such cases, an attempt was made to gain the information needed in a telephone interview. I found that as I became acquainted with the fishermen, the degree of cooperation increased considerably.

8.2.3.4.2 Range of Tag Recoveries. Tags were returned from a variety of locations. The most distant tag recoveries were made in a Hawaiian fish market by a Hawaiian fishery biologist from crabs air freighted from an Anacortes wholesaler. Several tags were returned from California, Oregon, and Idaho by people who had vacationed in the Kiket Island area. The most southern recapture was at Utsalady Point on Camano Island. A tag was recovered from a crab in an otter trawl catch landed at an Everett fish company. The exact location of the catch was uncertain but was possible Everett Bay.

Eight tags were returned as recoveries from Bellingham and Anacortes but were shown by interviews with the fishermen to have been recovered from Similk Bay, except one. The tagged crabs were mixed with other catches and reported as recoveries from these northern ports. One tag apparently was caught in Bellingham. If so, this recovery would represent the northernmost point of migration from Similk Bay.

8.2.3.4.3 Crab Migration in Similk Bay. A scattergram analysis was made of the distance traveled from point of release to point of recapture (*see* Fig. 8.2-14), the distance was plotted against the number of days out, and the curve was hand fitted. The pattern of movement indicates a tendency among the crabs to remain in the Similk Bay system. The crabs a-parently traveled away from the point of release in a circular fashion. The distance away from the point of release increases to the opposite side of the circle, then begins to decrease in a return to the point of release along a circular path.

This pattern is consistent with the findings in the analysis of tags recovered in less than 50 days. The time limitation restricted observations to those recoveries that could only have moved in a straight line away from

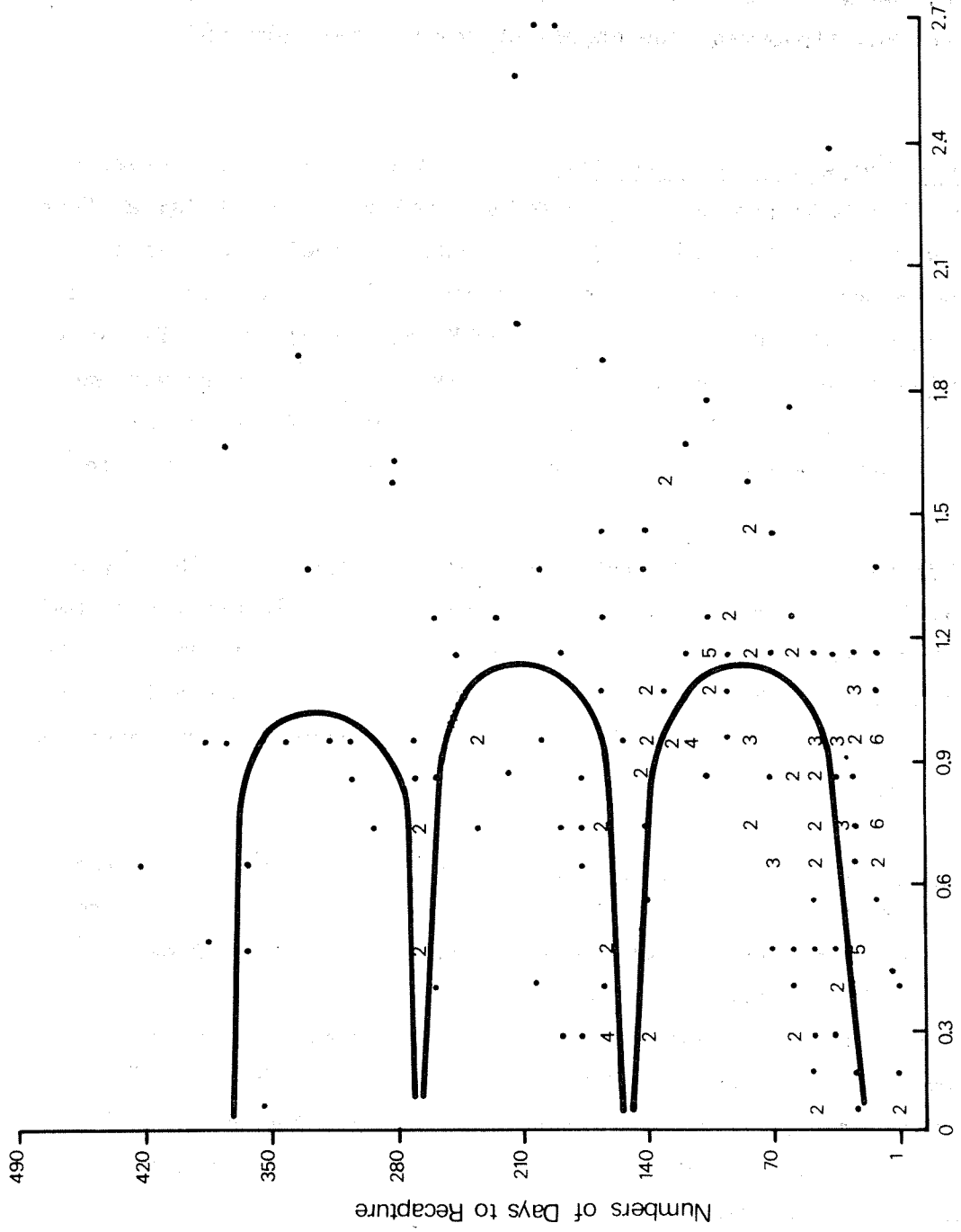


Fig. 8.2-14. A scattergram plot of the distance traveled from point of release to point of recovery of *C. magister* tagged in the study area against the time in days before recovery. The curve is hand-fitted to the distribution of points.

the release point. The summation vectors of the cases fitting the 50-day criterion are plotted by station in Fig. 8.2-15. Although the concentrations of fishing effort shown in Fig. 8.2-4 may have influenced the vector for station 6, the vectors at stations 1, 2, 3, 4, and 5 should have been relatively independent of fishing effort. The conflicting pattern seen at stations 7 and 8 is the result of a very small sample size. Although larger numbers of the crabs released at stations 7 and 8 were recovered in Similk Bay, only one of these was able to travel the distance into Similk Bay in less than 50 days.

The number or proportion of crabs leaving the Similk Bay population is unresolved in the present study. The lack of intensive fishing effort either outside Deception Pass or between Skagit Island and the Skagit River delta precludes any conclusions about the number of tagged crabs that left the Similk Bay area to enter these areas. The proportion of tagged crabs released from stations 7 and 8 that were recaptured to the south was significantly greater than the proportion of southern recoveries released from stations in Similk Bay.

8.2.3.4.4 Migration Pattern Based on Crab Tracks. Observations on the compass bearings of crab tracks at the eight sampling stations are graphically presented in Fig. 8.2-15. These results strongly bear out the migration pattern deduced from the analysis of tag returns. Because these observations were concentrated during the summer months, it is possible that seasonal differences in migration directions may exist. An examination of monthly tag recovery patterns indicated a prominent outmigration from Similk Bay during the months of April and May in 1971 and 1972. This pattern was the result of a marked increase in the number of recoveries in the recreational fishery west of Gibraltar Point. The recovery areas were primarily Dewey Beach and Coronet Bay.

8.2.3.4.5 Migration Model of Crabs in the Kiket Island Vicinity. A schematic model of crab migration was constructed based on the preceding evidence from long- and short-term tag recoveries and on observations of crab tracks. In Fig. 8.2-16 is shown the model formulated from recovery

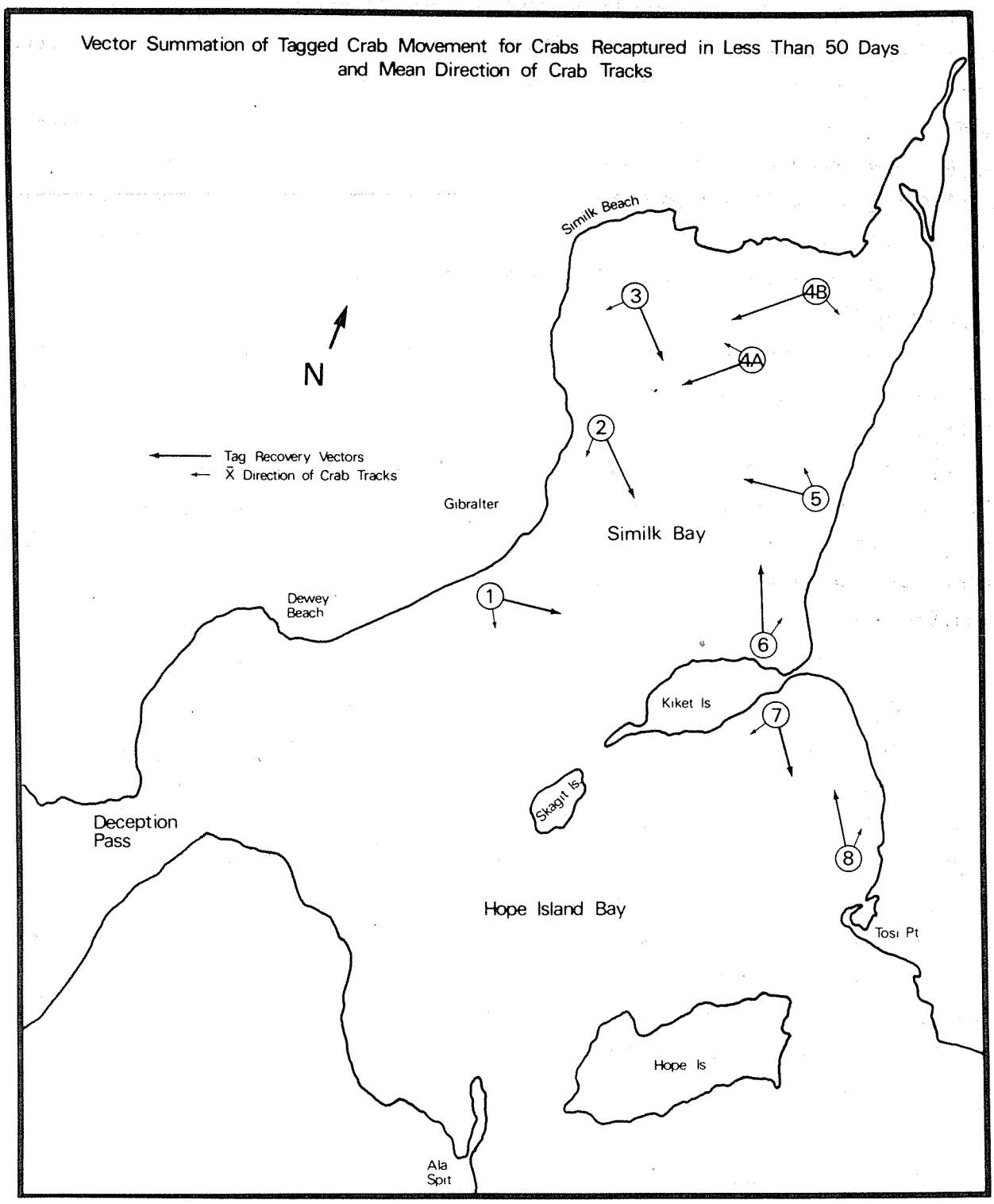


Fig. 8.2-15. A map of the study area showing the summation of migration vectors of tagged *C. magister* from the point of release to point of recovery for crabs recovered in less than 50 days. Included are the mean compass bearings of *C. magister* tracks observed by SCUBA at each sampling station during the period of June to August 1971.

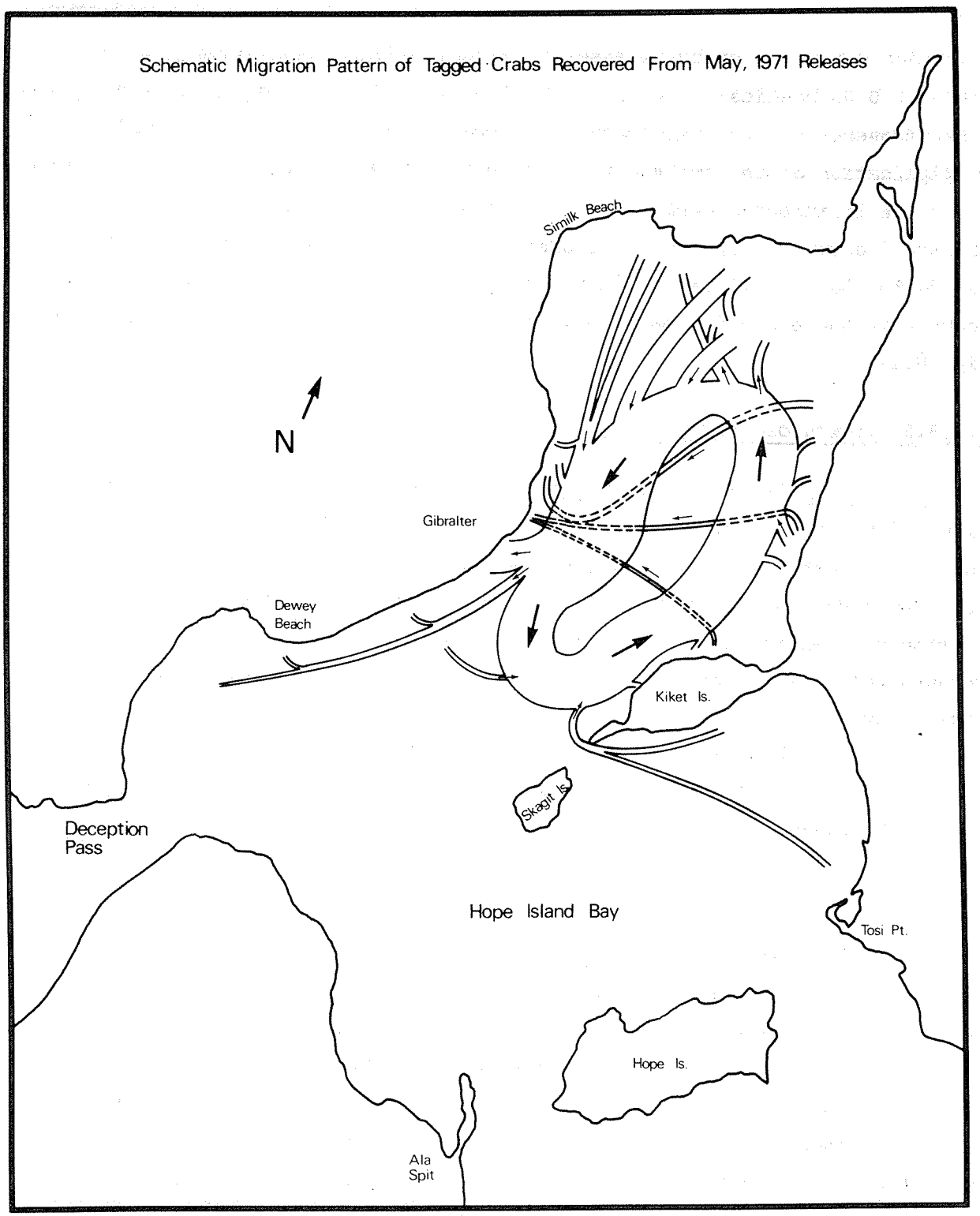


Fig. 8.2-16. A schematic representation of the migration pattern of *C. magister* in the study area based on tag returns from releases in May 1971. The widths of the paths are proportional to the number of crabs assumed to have followed the path.

information for the crabs released during May 1971. An average walking speed of 0.05 nautical miles/day (303 ft; 92.3 m) was calculated from straight-line recoveries. The crab recoveries were fitted to the circular model by multiplication of the average walking speed times the days out. The expected recapture locations determined from this calculation were very close to the points of actual recapture. The predicted time needed to complete a trip around the Bay is 130 days. This result agrees closely with the pattern deduced in the plot of time out vs distance traveled to recapture shown in Fig. 8.2-14.

8.2.3.5 Growth of Tagged Crabs

8.2.3.5.1 Growth of Tagged Crabs. Fifteen of the 349 tags returned from 2,046 releases were accompanied by carapace width information which indicated growth following release. No tagged crabs that showed growth were recovered in the study pots. Therefore all of the measured growth increases shown in Fig. 8.2-17 rely upon the accuracy of the fishermen's measurements. No estimate of the amount of error is possible. Among the tags returned from crabs which had not moulted, the mean absolute difference between the width at release and the width reproted by the fisherman was 0.14 inches (0.35 cm). This sort of error might be included in the growth increments shown in Fig. 8.2-17.

8.2.3.5.2 Width-weight Relationship of Similk Bay Crabs. The width-weight relationship of a sample of the catch from Similk Bay is plotted in Fig. 8.2-18. The sample size was not great enough at the smaller sizes (5.12 inches, 13.0 cm) to illustrate the step pattern normally seen in crustacea. The curve in Fig. 8.2-18 was smoothed by hand. At 6.1 to 6.3 inches (15.5-16.0 cm) there was a prominent step in the data suggesting a moulting period. This point corresponds to observations of soft-shell crabs in the catch of between 6.3 to 6.5 inches (16.0 to 16.4 cm). Based on the literature for crab populations of the outer coast (Poole, 1965), this would be equivalent to the 3-4 year-old moult (i.e., the age of legal-size recruitment).

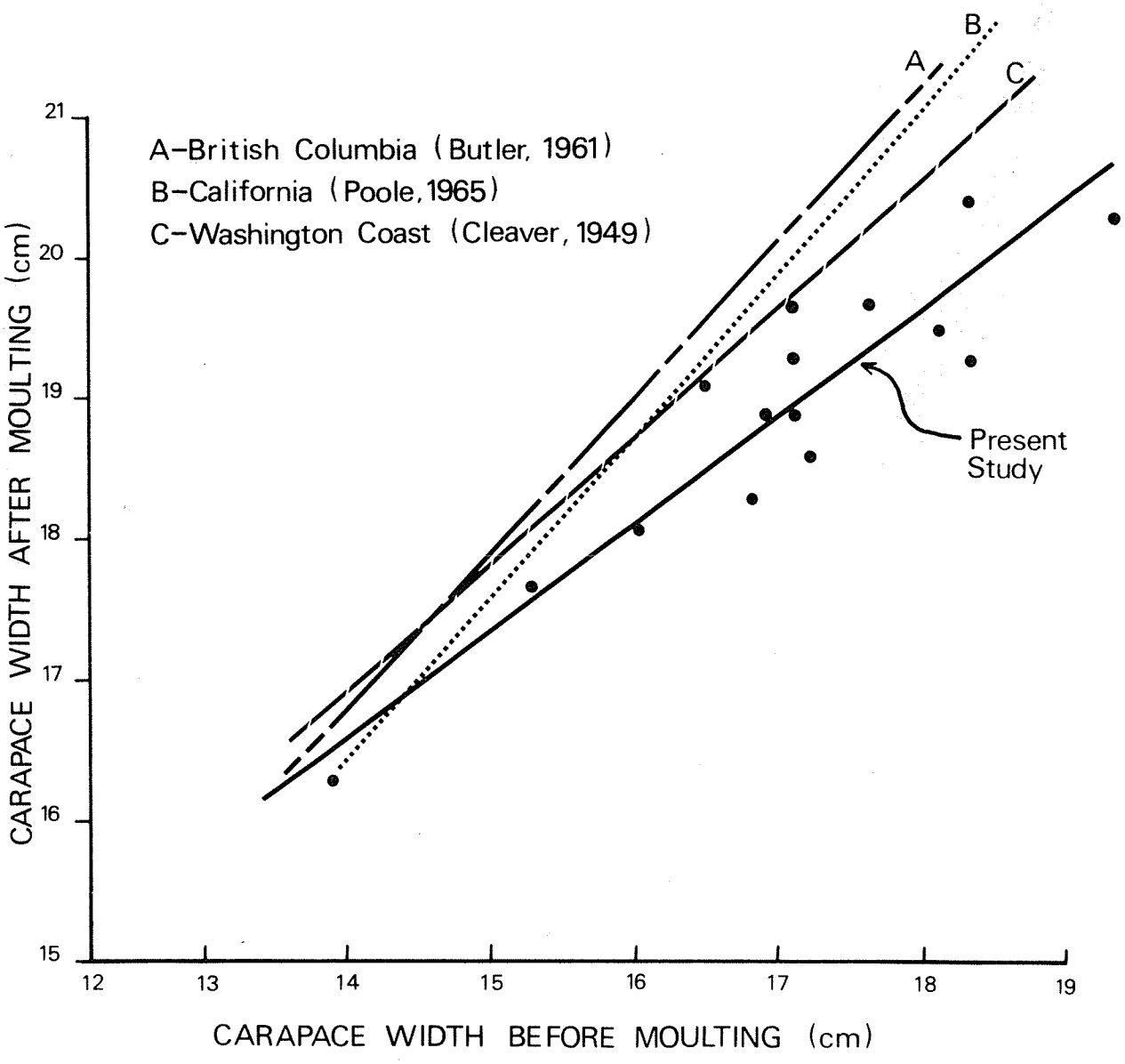


Fig. 8.2-17. A linear regression analysis of the increase in carapace width of tagged crabs which had moulted versus carapace width at time of release. The figure includes the results of similar growth studies. Carapace widths are exclusive of the 10th anterolateral teeth.

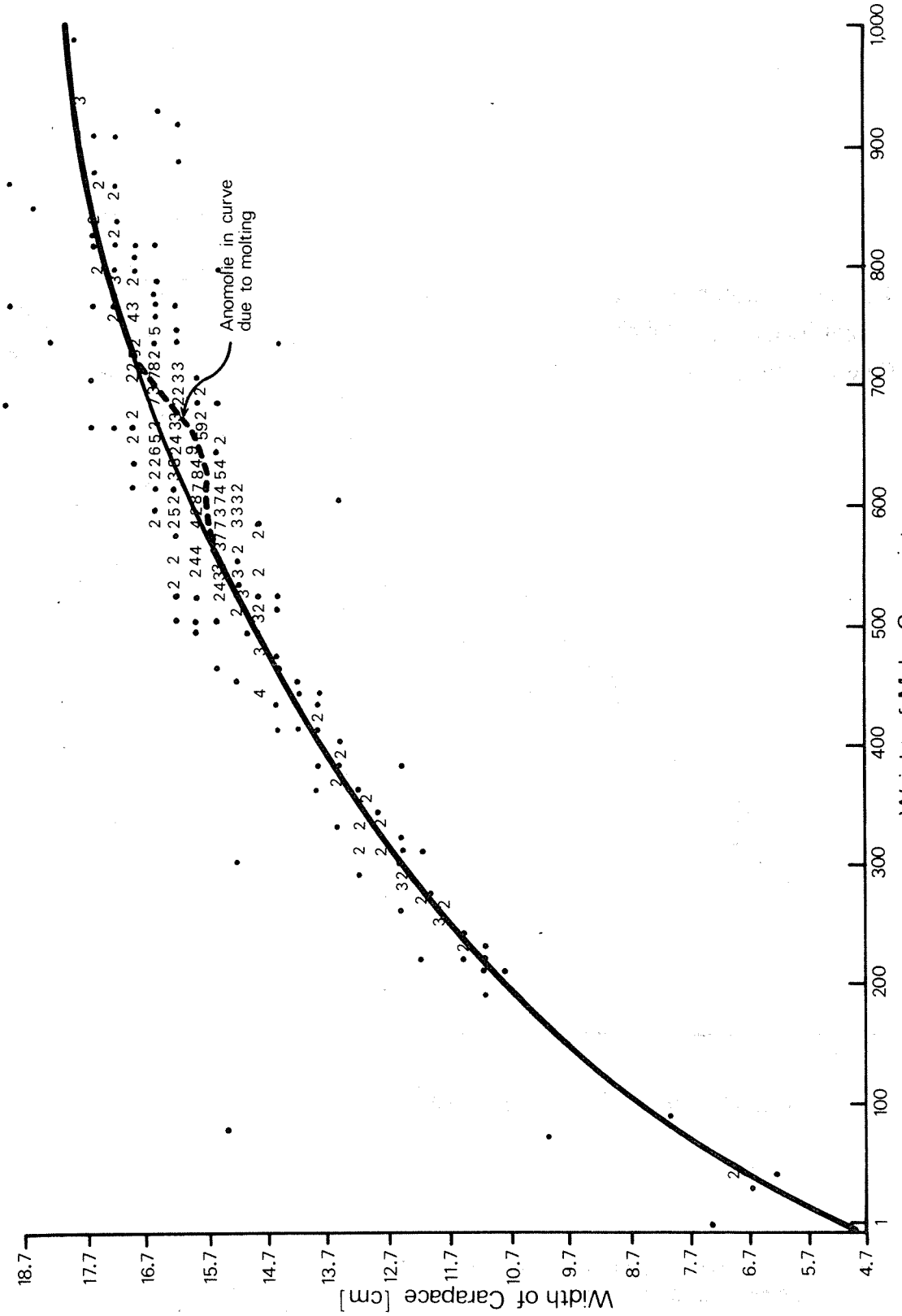


Fig. 8.2-18. The width-weight relationship for a sample of the *C. magister* caught in the study area during the period of July 1970 to September 1971. The curve was hand fitted.

8.2.4 Discussion

8.2.4.1 Crab Stock and Recruitment

8.2.4.1.1 Stock. The stock of Dungeness crabs in the Kiket Island area may be separated into two essentially distinct populations. Tag recoveries, indicated the existence of a resident crab population in Similk Bay and a broadly migratory population outside the Bay. A circular pattern of migrations within the Bay was also apparent, but no definite pattern emerged from tags released outside the Bay. A large number of tags were recovered in the northern part of the Bay, but this pattern may have been the result of concentration of fishing effort there.

8.2.4.1.2. Larval Recruitment. No direct assessment was made of either the distribution or abundance of crab larvae in the study, but some speculation is possible about the potential recruitment to the area. Based on laboratory studies by Reed (1969) the survival of *C. magister* larvae in the Kiket Island area may be less than along the outer coast. Reed (1969) found that the optimum ranges of salinity and temperature for Dungeness larvae are 25-30 ^{o}/oo and 10-13.5 C, respectively. Based on the occurrence of female crabs with hatched egg masses, the hatching period in Similk Bay is between February and May. During this period salinities are often reduced by high discharge from the Skagit River (*see* 4.0 SEASONAL WATER QUALITY). From Reed's findings the water quality is much less than optimum for larval survival. However, large numbers of megalops larvae were collected in plankton samples during the period of June to August. The exchange of water from Rosario Straits may be great enough to replenish constantly the water around Kiket Island and bring in a steady supply of viable *C. magister* larvae during the late summer months when salinities are favorable.

8.2.4.1.3 Intertidal Recruitment. Houghton (personal communication) found a total of five juvenile crabs in 311 1/4 m^2 quadrat samples. The samples were collected between mean sea level and -6 ft (-1.8 m). The crabs averaged 2.5 inches (6.75 cm) in width including the tenth anterolateral teeth and were collected in January and July 1970 and January 1971. An extrapolation of this measured density to an estimate of the standing crop in the intertidal

of Kiket Island produced an estimated standing crop of 1,016 crabs. The length of intertidal shoreline around Kiket Island is approximately one-fourth of the total shoreline between Dewey Point and Tosi Point including the shorelines of Skagit and Hope Islands. Based on this proportion, a further extrapolation produced an estimated total of 4,100 juvenile Dungeness crabs in the intertidal of the Kiket Island study region.

Trawl samples collected with a trynet 10 ft (3.0 m) wide at 26-32.8 ft (8-10 m) failed to include a single Dungeness crab less than 3.9 inches (10 cm). The gear was similar to that used by Poole (1965) and Butler (1956) which caught large numbers of juvenile crabs in their study areas. Fishing was conducted every two months over a period of two years. The absence of juvenile crabs except for those taken intertidally would indicate that local juvenile production plays only a small role in recruitment and that the major source is immigration into Similk Bay.

8.2.4.2 Migrations of Crabs

Personal communication with local crab fishermen indicated that many believed that large numbers of juvenile crabs are present in the region of the Skagit River delta. Crabs are reported to be positively rheotactic (McKay, 1942). In terms of the crab's energy conservation, it would be most efficient to move with the current rather than against it. The hydrography of the Skagit River delta can be characterized as an advection system (Barnes, personal communication). The movement of the Skagit River surface water advects large net flows of dense bottom water toward Deception Pass. If crabs travel in the direction of the prevailing currents, the hydrography of the study area would result in a net transport of crabs toward Deception Pass.

The crabs would move along the south shore of Kiket Island and into the pass between Kiket and Skagit Islands. The ebbing tide would carry the crabs through the pass. The majority would make the passage along the east side of the pass and arrive on the other side of the pass in Similk Bay. Once through the pass, these crabs might immediately turn up into Similk Bay or continue across the mouth of Similk Bay toward the west shore. The crabs traveling across the mouth of Similk Bay would reach the west shore where

the current is divided. Since they are on the north side of the current, they would bear north with this branch into the Bay. It seems possible that Similk Bay acts as a trap for the crabs moving through the pass between Skagit and Kiket Islands. Once inside the Similk Bay system the crabs would remain semitrapped by the same current patterns that directed them there. The net counter clockwise direction of current flow in Similk Bay (Barnes, personal communication) would explain the counter-clockwise migration of crabs. The tidal currents might keep the crabs in Similk Bay and simultaneously bring new crabs into the Bay. This intuitive behavioral model is consistent with the results of the crab tagging studies. It agrees with the seemingly closed nature of the crab population of Similk Bay.

8.2.4.3 Exploitation of the Crab Resource

The average monthly fishing mortality is 21 per cent for the Kiket Island crab stock. The level of exploitation is high compared to that of coastal crab populations. At this level 100 per cent of the legal-size crabs are harvested every 6 months. The number of crabs harvested from Kiket Island as estimated from survey questionnaires was approximately 6,000. Assuming that there might have been as many as 2,000 more crabs that were harvested but not recorded in the survey, we would venture to estimate that the total annual harvest of legal-size crabs could be as high as 8,000. From the width-frequency distribution of the study catch, approximately 40 per cent of the catch consisted of legal-size males. Using the Similk Bay population estimate of 10,500 crabs, we would estimate that the number of legal size crabs would be 4,020. The measured mortality from fishing in this number of legal-size crabs would be close to the annual harvest reported in the questionnaires. These results would also support the hypothesis that the harvest is sustained by the constant recruitment through immigration of adult crabs into the area.

Cleaver (1949) reported that the Washington coastal fishery took 78 and 87 per cent of the crabs on the grounds in 1947 and 1948, respectively. Butler (1951) found an exploitation rate of 33 per cent for Naden Harbor and 4 to 23 per cent in other areas in 1948 and 1949. The high rate around Kiket Island is due to participation in the harvest by commercial fishermen. Recreational harvest is a function of the amount that can be personally consumed, thus its level remains low and relatively constant.

In Similk Bay fishing mortality is limited by the presence of tug boats in the center of the Bay and the operations of a gill net fishery along the north shore of Kiket Island during the early summer months. An estimate of the maximum sustainable yield for the area would require knowledge of recruitment and/or a CPUE and effort analysis for a number of years.

8.2.4.4 Natural Mortality

8.2.4.4.1 General. Natural mortality accounted for approximately 50 per cent of the average total monthly mortality, but its source is little known. Frequently during the summer months dead adult crabs were observed in intertidal drift. These mortalities may have been caused by disease brought on by warmer summer temperatures or depletion of the oxygen in the shallow water at nighttime.

8.2.4.4.2 Mortality from Low Salinity. A large number of dead adult crabs were found in the station 3-B crab pot, the shallowest station, during March 1972. A sharp increase in the Skagit River discharge had taken place prior to this observation (*see* section 4.0). It is possible that the crabs had been caught in the trap prior to the large discharge and were trapped in the low salinity floodwater. The March mortalities may have been due to a combination of low temperatures and a rapid decline in salinity, since crabs were frequently caught in good condition at this station during periods of lower salinities in late summer. Mortality due to rapid environmental changes is a probable source of natural mortality but is certainly moderated by the crabs' ability to migrate to more favorable conditions.

8.2.4.4.3 Mortality from Disease. A single disease reported for the Dungeness crab, "black spot" or "rust spot" is occasionally found on the legs. Although this disease has not been specifically described for the Dungeness crab, it may be similar to the disease caused by chitonivorous bacteria in the European edible crab, *Cancer pagurus* (Sinderman, 1967). Records of the occurrence of "black spot" in Kiket Island crabs were kept from June 1971 to September 1972, and the disease was observed in 0.92 per cent of the crabs taken during this period. Bell and Hoskins (1966) described the lethal results of experimentally introduced lobster pathogen, *Gaffkya homari*, in *C. magister*; but this pathogen is not known to occur naturally in *C. magister*. No parasites

are known to infest *C. magister*. McKay (1942) reported observing worms adhering to the carapace and egg masses. Sinderman (1967) later concluded that the worms may have been marine leeches.

8.2.4.4.4 Mortality from Predation. Very little is known about the contribution of predation to the natural mortality rates of the Dungeness crab. McKay (1942) cites observations of *C. magister* larvae commonly found in the stomachs of salmon, herring, and pilchard. Cannibalism is common in *C. magister* beyond the megalops stage (Waldron, 1958). Butler (1954) reports the common occurrence of juvenile crabs about 3/8 inch (0.95 cm) in width in the stomachs of adult crabs.

McMynn (1951) reported the presence of large numbers of juvenile Dungeness crabs in the stomachs of "wolf-eels," *Anarrhichthys ocellatus*, captured in crab pots. He also found numerous small crabs in the stomachs of approximately 20 halibut, *Hippoglossus stenolepis*. Waldron (1958) found lingcod, *Ophiodon elongatus*; the great marbled sculpin, *Scorpaenichithys marmoratus*; wolf-eels; halibut; and some of the rockfishes, *Sebastes* spp., to be voracious predators of adult Dungeness crabs. McMynn (1951) observed two Dungeness crabs 4.5 inches (11.4 cm) wide and four other smaller crabs in the stomach of one great marbled sculpin. Rockfish were commonly taken in otter trawl samples in Hope Island Bay and Skagit Bay-West (*see* Fig. 9-1). On several occasions the stomach contents were casually examined and large numbers of adult *Cancer gracilis* were frequently seen. Only a single, small Dungeness crab 3.9 inches (10 cm) was found by the author in all of the stomachs examined by him. It seems unlikely that any of the fish caught in the otter trawl samples because of their size could devour an adult Dungeness crab.

8.2.4.4.5 Mortality from Moulting. The increase in the measured rates of mortality during March, April, and May in 1971 and 1972 may represent a seasonal increase in natural mortality. Cleaver (1949) found that the percentage of recoveries of tagged soft-shelled crabs and crabs with missing appendages was much lower than that of hard-shelled crabs. This finding may indicate a higher natural mortality when the crabs are in a soft-shell condition or have missing appendages. Additional information on the sources of natural mortality is necessary before future conclusions can be reached on this aspect of the Kiket Island crab population.

8.2.4.5 Use of Population Parameters to Monitor Environmental Change

Estimates of survival, mortality rates, and population abundance all have error from different sources. The Seber-Jolly method of mark-and-recapture analysis suffers less bias than other mark-and-recapture methods, but the population estimate is based on a number of assumptions. The estimate is positively biased by nonrecovery and/or nonreporting of tags and loss of tags. Loss of tags was estimated from the results of the 1971 experiment in tag retention and applied to recovery data, but no estimate was made as to the rate of nonreporting or nonrecovery in the fishery. In addition the total number of untagged crabs caught was estimated from log sheet information on the numbers of untagged crabs caught and in cases where tags were returned without this information by the use of a proportion factor estimated from the study catch, and the study catch itself. Errors obviously existed in the first two sources of catch information. It is felt that the total number of untagged crabs caught may be underestimated, and therefore the population estimate is negatively biased.

Survival and mortality rates estimated by the Seber-Jolly method are not affected, however, by the abovementioned sources of bias, and therefore are the least biased of the population parameters. These parameters should prove to be useful indices to the postoperational effect of industrial wastes. In addition, natural fluctuations in crab population abundances are known to be enormous (*see* Figs. 8.2-1 and 8.2-2). The declines and increases in both the coastal and Puget Sound populations occur in seemingly regular fashion. Someday these fluctuations may be understood from environmental changes or population dynamics. Until these relationships are understood and can be predicted, the assessment of the impact of wastes on the abundance of a particular crab population will be very difficult.

8.2.4.6 CPUE versus Population Estimates

The relationship between the crab population estimates from mark-and-recapture results and CPUE in study crab pots was significant at only the 90 per cent confidence level. The short-term monthly or bimonthly population estimates are subject to fairly large errors due to the small numbers of tags released in certain months and subsequently small numbers of recoveries.

The estimates may also be influenced by an error in the recovery date either in the fishermen's report or my estimate of the date when no date was reported. Because of the repeatability of seasonal trends in CPUE, it is felt that the statistic represents a useful index for future comparisons. Cleaver (1949) found a seemingly strong relationship between CPUE and abundance of a crab population. His findings were based on the results of carefully kept fishermen log books. A log book system would have improved the present study.

8.2.4.7 CPUE of Study Pots versus CPUE of Local Fishery

The study CPUE and the CPUE estimated for the sport and commercial fishermen agree closely. This agreement is interesting since the study pots were unbaited and all the fishermen's pots were baited. A similar finding was reported by McKay (1942) in his study of an old crab fishery in Boundary Bay. The fishermen had not used bait in their traps for 25-30 yr. He tested baited traps against unbaited traps and found that there were actually fewer numbers of legal-size crabs in baited traps than unbaited traps. He concluded that there was no significant difference between his CPUE and that of commercial fishermen using bait.

If the crabs learn at earlier stages in life that a trap represents food, companionship, or cover on an otherwise plain bottom, they may continue to enter an unbaited trap out of habit. At smaller sizes they are able to explore a trap without the risk of being caught. The escape rates in the present study demonstrate that crabs are able to enter and leave a pot with relative ease. When sublegal crabs are in a trap when it is lifted, they suffer no greater risk than a toss back into the water. McKay (1942) concluded that the baited traps were successful because of the high density and exploratory behavior of crabs.

The overall adjusted CPUE of 1.12 crabs/pot/day (c/p/d) is lower than in other studies reported in the literature. Cleaver (1949) reported a CPUE of 2.6-3.9 c/p/d in the Washington coastal fishery. McMynn (1951) found a CPUE of 1.5-3.0 in the crab fishery of Graham Island, B.C. The lower CPUE in the Kiket Island area probably indicates a lower crab density than in the above study areas.

8.2.4.8 CPUE versus Temperature and Salinity

The abundance of *C. magister* in shallow water shown by the CPUE was significantly correlated with water temperature. As described in an earlier section, an observed increase in mortality of trapped crabs was associated with periods of very low salinities and temperatures. The CPUE also appeared to fluctuate in response to drops in salinity during these periods. One problem in testing the correlation between CPUE and temperature or salinity is the delay and overlap of measurement periods for each variable. Salinity was measured on a less regular basis than temperature. Monthly variations in salinities were greater than those in water temperatures.

Although salinity measurements were not taken in conjunction with the catch at the eight samplings, some semiquantitative relationship was seen in the analysis of CPUE. Isopleths fitted to surface salinities in Similk Bay produced a number of prevailing patterns. As seen in Fig. 4-17, the salinity patterns during flood in the summer months show a higher salinity on the north side of Similk Bay. This increase is probably the result of an intrusion of deep saline water along a channel in the area. Evaporation in the upper end of Similk Bay may increase further the salinity in this area. CPUE was consistently highest among commercial fishermen in this area. Although not statistically significant, the CPUE of study pots, shown in Fig. 8.2-6, also followed this trend. The crabs may favor the north side of the Bay due to the more nearly oceanic conditions in the region.

The correlation of CPUE with water temperature may be in fact an indirect correlation with some other variable. Des Voignes (personal communication) found that photoperiod played an important role in the thermal tolerance and mortality of the Dungeness crab. Water temperatures are closely associated with photoperiod. Photoperiod may be the direct cause in fluctuations in CPUE. McKay (1942) felt that the controlling factor in the seasonal movement of crab is temperature. He observed that the crabs avoided areas of warm brackish water. In contrast, in the present study the highest CPUE was associated with the warmest water temperatures.

8.2.4.9 CPUE and Migrations

The fluctuations in the availability of crabs measured by the CPUE may have been the result of crab migrations. SCUBA observations in the fishing

area during the periods of low CPUE established a marked decline in the number of crabs observed on the grounds. The otter trawl catches of Dungeness crab from the deeper portions of the study areas are shown in Fig. 8.3-10. The increases in numbers caught occurred simultaneously with increases in the CPUE of crab traps in Similk Bay. If there was a seasonal migration of crabs in and out of Similk Bay, the catches in crab pots and deep-water trawling should be out of phase. The results of trawling in Similk Bay show a tendency toward this relationship in the late winter and spring months. It is possible that the crabs in the shallow water areas make small-scale migrations out of the low-salinity nearshore water into the higher-salinity water in deeper portions of the Bay. Some movement of this sort is suggested by the pattern in otter trawl catches in Skagit Bay-West (*see* Fig. 9-1). This station showed increased crab catches before either the Hope Island Bay station or the Similk Bay station. It is felt, however, that the major reason for the fluctuations in crab catches is a seasonal change in crab activity.

Feeding activity might also have caused changes in the CPUE. Des Voignes (personal communication) found that the feeding activity of crabs declined and nearly ceased with decreasing photoperiod. McKay (1942) and Cleaver (1949) reported a winter increase in the occurrence of crabs burrowed into the bottom. Crabs held in underwater pens in the present study were frequently burrowed in the sediments during the winter. Divers' observations of the absence of crabs from the fishing grounds during the winter months may have resulted from the crabs' burrowing behavior.

Several authors have discussed the possibilities of crab migrations. Seasonal offshore-onshore movements of *C. pagurus* appear to be well established (McKay, 1942). McKay (1942) could not find a similar pattern in the populations of *C. magister* he studied. Cleaver (1949) postulated a northerly summer movement of crabs along the coast and a possible return migration in deeper waters. He also noted that the larger crabs retreated before a freshet. Waldron (1958) could find no consistent pattern in the movement of tagged crabs along the Oregon coast. Some areas showed a significant northern migration component. He was, however, unable to separate the possible influence of the disproportionate location of fishing effort.

8.2.4.10 Growth Rate of Tagged Crabs

8.2.4.10.1 General. It seems commonly accepted among crab fishermen that the crabs in Puget Sound are smaller in average size than the coastal crabs. This belief is generally borne out by a comparison of the average weight per individual of crabs landed in Puget Sound with those landed in the coastal fishery. The conversion factor of total weight to total numbers of Puget Sound crabs used by the Washington State Department of Fisheries is 1.83 lb/individual (0.83 kg). Puget Sound catch statistics since 1943 have been based on this conversion factor. Similar statistics for the coastal fishery show a variance in the weight-to-numbers ratio from year to year. Without knowing the variance about the average conversion factor applied to Puget Sound catches, one cannot make a statistical comparison between average individual weight of the coastal and Puget Sound crabs. The average weight of Puget Sound crabs is, however, within the range of the maximum and minimum average annual weights of coastal crabs. There is apparently no study in the literature to substantiate the difference in size or growth rate of Puget Sound and coastal crabs. Waldron (1958) observed that the Oregon bay crabs were usually smaller than Kiket Island crabs.

8.2.4.10.2 Growth in Kiket Island Crabs. If it can be assumed that the time between moulting was the same for the various crab populations sampled and compared in Fig. 8.2-17, then the results of the present study demonstrate a slower growth rate for Kiket Island crabs than has been observed for coastal crabs. The assumption of the number of moults per unit time is a serious problem, however, in growth studies of crustaceans. If moulting cycles in adult crabs are primarily seasonal as most authors have indicated (McKay, 1942; Cleaver, 1949), a comparison of growth increments may be a valid index to growth rates. It is likely then that the smaller growth increment per moult seen in the Kiket Island crabs represents a growth rate that is slower than that of the coastal populations cited in Fig. 8.2-17.

8.2.4.10.3 Possible Influences in Growth Rate. There are several possible explanations for the slower growth rate of the Kiket Island crabs compared with the coastal crabs. It may result from the loss of energy to increased

physiological demands of an estuarine environment. Though the Dungeness crab is an oceanic species, its osmoregulatory processes are obviously capable of handling conditions of low salinity. Energy would be diverted from growth to osmoregulatory processes in low salinities. The quantity and or quality of the food resource may also play a role in the comparatively slow growth of Kiket Island crabs.

The standing crop, dry weight biomass, of the coastal benthos is 2.00 g/m^2 (Lie, 1969), one-fourth that of the Kiket Island area (average of 8.50 g/m^2). Lie (1969) reported standing crops, dry weight, in other areas of Puget Sound ranging from 8-12 g/m^2. Although the benthic standing crop is lower, the crabs prey items may occur in larger sizes along the coast. The larger the prey up to the size that can be captured, the more efficient the crab becomes at accumulation of energy for growth or reproduction. The results of stomach analysis of crabs sampled from the Kiket Island area (discussed in a following section) are similar to those of studies of diet reported by others (Butler, 1951; McKay, 1942). A noticeable exception is the lack of juvenile Dungeness crabs and large clam parts in the stomach samples of Kiket Island crabs.

8.2.4.10.4 Growth and Population Dynamics. The cyclic fluctuations in the Dungeness crab populations follow an 8-10 year pulse (*see* Fig. 8.2-2). This period would not normally fit into a spawner-recruit relationship since the maturation period is between 3 and 5 years. Density-dependent mortality based on the crabs' cannibalistic feeding could account for this inverse relationship. Crab larvae spawned by the lowest adult stock density would settle to the bottom among the lowest density of adult crabs. They would be recruited into the fishery 4 to 5 years later after having suffered the least prerecruit mortality from cannibalism. The lowest prerecruit mortality would result in the highest adult recruitment and harvest 4-5 years later. An inverse spawner-recruit relationship resulting from cannibalism would closely fit the abundance cycles seen in Fig. 8.2-2. The presence of large numbers of subadult crabs on the coastal grounds may provide an enriched food resource compared with that at Kiket Island and possibly Puget Sound. This additional food resource may account for the higher growth rates of coastal crabs.

8.2.5 Summary and Conclusions

1) Information for *C. magister* included (a) description of a definite migration pattern, (b) growth rate in Puget Sound, (c) catch per unit effort in a Puget Sound crab fishery, (d) the seasonal changes in and effect of water conditions on crab catchability, (e) crab escape rates from pots, and (f) the relationship between crab egg production and size of female. The questionnaire survey and description of the recreational and commercial crab fishermen represents useful background information.

2) The Dungeness crabs in Similk Bay are harvested at a high rate due to the concentration of recreational and commercial effort and the trapping effect of the Similk Bay hydrography. It is felt that this harvest is sustained by a constant immigration of crabs from the less exploited areas to the south.

3) The crab fishery in the study area represents a renewable resource that annually yields an estimated retail value of $11,000 worth of crab (1972). The harvest is divided one-third and two-third, respectively, to the recreational fishery and the commercial fishery.

4) The average catch per unit effort was lower than reported in coastal crab fisheries.

5) Increases in catch per unit effort were significantly related to increasing water temperatures. However, some other environmental factor associated with water temperature may actually be responsible for the observed increases in the CPUE, i.e., photoperiod, food supply, etc.

6) The total number of crabs between 5.3 and 6.3 inches (13.5 and 18.5 cm) in width in the study area was estimated to be 14,500 ($\pm$ 5,500).

7) The growth of tagged crabs released and recovered in the Kiket Island vicinity was lower than growth rates reported in coastal crab studies.

8) The release and recovery of tagged crabs showed distinct counterclockwise crab migration in Similk Bay. This finding was supported by SCUBA observations of crab tracks.

9) Measured survival and mortality rates estimated for the crab population represent baseline statistics which could prove useful in assessing the effect of any environmental degradation on the population. Population

estimates proved to be highly variable and poorly correlated to CPUE. In view of the known natural fluctuations in crab abundances, crab population estimates would be of little value in monitoring the effect of waste discharge. Emphasis is therefore placed on mortality rates for evaluating waste impact.

10) It was reasoned that crab larvae played a minor role in the recruitment of the adult stocks in the Kiket Island vicinity. Recruitment is apparently achieved by immigration of mature crabs into the area. This finding suggests that the removal of crab larvae by a power plant intake or discharge filter would have little effect on adult crab recruitment to the local fishery.

11) Based on the results in the crab thermal gradient studies (*see* section 10.3), the crab's preferred summer temperature was 56 F (13.3 C) and preferred winter temperature was 52 F (11.4 C), a thermal addition to the shallow areas which made the water temperatures more attractive might draw crabs into the intensive nearshore crab fishery.

8.3 BENTHIC INVERTEBRATE COMMUNITY AND DUNGENESS CRAB INTERACTIONS

8.3.1 Objectives

There were two objectives in the collection of information on the subtidal invertebrate community. The first intent was to collect a body of data that would document the occurrence, abundance, and seasonality of the assemblage of infauna species. A justification frequently argued for this approach is that if the operation of a power plant in the vicinity caused the degradation of the subtidal habitat, it would be reflected in changes of faunal composition and or abundance. A time period of study of appropriate length was necessary for the normal extent of these changes within and between years to be realized.

The second objective was to develop an understanding of community among the collected assemblage of species and to examine the application of such a concept to the problems of environmental change. The approach was to focus the assessment of thermal sensitivity of the subtidal community on a single species, the Dungeness crab, because of its widespread occurrence in the community and its suspected role as a top-level consumer. If the Dungeness crab's response to elevated temperatures could be determined in the laboratory, the outcome of these environmental changes on the crab population could be predicted and, in turn, the secondary effects on the composition of the infauna.

8.3.2 Review of the Literature

8.3.2.1 Benthic Community Concept

Studies of the benthic fauna of Puget Sound were completely lacking until those of Lie (1968). Lie surveyed a number of benthic stations lying on a transect across the width of Puget Sound in the Seattle region. Hobson and Banse (1972) subsequently produced a key to the Puget Sound polychaetes based on many specimens from Lie's collections. Lie examined faunal changes across season and depth in terms of numbers and diversity indices. His work forms the primary background for the present study. The primary effort of the study centered on the assemblage and identification of an invertebrate reference collection. Many species were new or unreported for the area.

Investigations into the problems of benthic community description are not new. Verrill (1874), one of the first American benthologists, recognized benthic faunal groups characteristic of estuaries, bays, and deep offshore areas in his studies in Martha's Vineyard. Petersen (1913, 1915, 1918), who might well be called the father of the community concept, first described a benthic community from the waters of the Limfjord. He found that the communities occurred in "zones or areas of uniformity," but were not attributable to a single factor. Borrowing from contemporary plant ecologists, he applied community terminology to his statistical units. The community was named with a combination of the generic name of the most numerically dominant animal and the specific name of the second most dominant species. Thorson (1957) later revised this somewhat confusing classification system. Petersen believed that subtle gradations exist between separate communities and, therefore, rejected the biocoenosis theories of Mobius. As Petersen extended his investigations into other geographical areas, he discovered the process of defining communities from rocky bottom to be overwhelmingly difficult. He recognized the complexity of these areas and returned to areas of mud bottom.

Molander (1928), using Petersen's sampling methods in the Gullmar Fjord, was unable to find the same pairs of species that Petersen had used to characterize his communities. Molander felt that his findings represented facies in Petersen's communities. He disagreed with Petersen's views on the importance of competition and sediments in the occurrence of a community and believed that temperature and salinity are the important controlling factors. Lindroth (1935) replicated Molander's study in the same fjord, but instead of considering just a few characteristic species in the sample as Molander had done, he included all species collected. He concluded that no distinct boundaries existed between communities as Molander had proposed.

Thorson (1966) argued for a revival of Petersen's approach to community description but pointed out the shortcomings of the approach. He stressed the importance of selecting characteristic species that strongly reflect meaningful biological relations within the community and its environment. He emphasized the importance of a thorough knowledge of the population dynamics, particularly larval recruitment to the community. In his laboratory

studies of larval ecology of marine benthic invertebrates he demonstrated the role of biotic parameters in determining community composition and distribution.

Ford (1923) in his investigations in the British Channel, demonstrated the relationship between bottom complexity and species diversity. His argument that complex environmental conditions favor species diversity proved to be a forerunner of present-day concepts of the relationship between niche diversity and species diversity. Davies (1925) reemphasized the relationship of sediment types and bottom communities. This attitude led Jones (1950) to propose a system of community classification based on depth, sediments, and geographical distribution.

Sanders (1956) continued the American studies of marine benthic communities in his studies in Long Island Sound. He discovered strong relationships between the quality of sediment and biomass of infauna. His careful seasonal measurements of weights and numbers of species allowed him to make estimates of the benthic production. Sanders (1969) later became interested in the problems of benthic diversity and formulated the stability-time hypothesis to account for increase in species diversity with increase in depth.

Benthic marine community studies along the Pacific coast were nearly lacking until recently. Barnard, Hartman, and Jones (1959) conducted extensive surveys along the Southern California coast. Their work contributed largely to the problems of infauna taxonomy and laid the groundwork for community analysis. On a smaller scale, Jones (1961) collected numerous core samples in the San Francisco Bay across several seasons at permanent sampling locations. His approach formed the basis for the use of core samples in the present study. Jones examined the seasonal changes in sample diversity and the coefficients of dispersion for several species. He did not attempt to describe benthic communities for the area.

McNulty, Work, and Moore (1962) described benthic communities from analysis of samples from 180 stations in Biscayne Bay. They delineated community boundaries on the basis of a coefficient of concurrence. Through matrix analysis of species concurrence, communities of species based on convergent coefficients were identified. The concurring groups were plotted against sediment types. The extracted assemblages or communities were then characterized by the preferred sediment type.

Fager and McGowan (1963), in their studies of zooplankton populations, discovered recurring associations of species that closely paralleled particular sets of hydrographic conditions. In his benthic studies of the nearshore environment in Southern California, Fager (1957, 1968) attempted to find similar correlations between recurring groups and environmental conditions. He reasoned that recurrent groups are enclosed in a space defined by environmental parameters. Although a complete set of these environmental spatial dimensions is practically unobtainable, the affinity between groups may be indexed and tested. Fager hoped that with a large body of synecological data, one could separate the statistically defined groups of recurring species and correlate them with environmental parameters. The result of his nearshore study was that, in spite of the vigorous nature of the environment, the assemblage of recurring species was surprisingly stable.

In his recent work Lie (1968) discussed many of the above ideas and progress of community analysis. His methods introduced a new level of community analysis. Some of them are applied in the present study. Lie successfully adapted the statistical technique of principle component and multivariate analysis to the task of defining benthic communities. Seal (1964) reviewed the application of multivariate analysis to biology up to that time. More recent examples of multivariate analysis of marine benthic communities include Cassie and Michael's (1968) study of a New Zealand mudflat and Lie and Kelley's (1970) study of the benthic fauna along Washington's coast.

While much research continues to be devoted to the manner and methods of community analysis, the present study relies upon the multivariate analysis for data treatment. The study was designed as a test of the response of a benthic community or assemblage to a manipulated source of predation. Since the Dungeness crab is a predator on infauna populations, it was hoped to manipulate predation from this source and measure the response of the infauna in their environment by multivariate techniques as if the analysis were to separate communities.

8.3.2.2 Community Manipulation

Blevgad (1927) was one of the earliest benthologists to make use of physical manipulations to examine the relationship of the benthic infauna to predation. He attempted to estimate the effects of fish predation

(mainly plaice) on the benthos by enclosing portions of the mud bottom with protective cages. Blevgad reported a sixtyfold increase in the numbers of invertebrates per unit area in the absence of fish predation. Unfortunately he did not mention the changes in faunal composition that occurred in the absence of predation. In terrestrial studies of grazing effects, grazed and ungrazed lands are typically compared (Clements, 1934). Pearson (1965) compared two grazed and ungrazed grasslands in rate of primary production.

Haynê and Ball (1956) investigated the role of freshwater fish predation on benthic production. By controlling predation rates in small ponds, measuring benthic standing stocks, and fish biomass accumulation, they found that predation increased benthic production seventeen times. Randall (1965) prevented reef fishes from preying on selected algal stands by removing rocky causeways to the islands of algae on the sand bottoms and found that larger forms of algae began growing.

The effect of predation on a community's composition and structure has been studied and discussed recently by several authors. Kajak (1963, 1964) used underwater cages to remove fish predation from benthic infauna in Polish lakes and obtained results suggesting that predation had increased the community diversity by permitting the coexistence of prey items. Dayton (1970) showed that the competition for space between *Chthalamus stellatus* and *Balanus glandula* would normally be won by *B. glandula*. The selective predation of *Thais lamellosa* and *Pisaster ochraceus* on *B. glandula* reduced the barnacles' competitive advantage to a level that permitted the coexistence of the two barnacle species. Connell (1970) demonstrated that predation by *Thais lamellosa* and *Thais emarginata* on *B. glandula* had restricted its distribution to a narrow refuge in the upper tidal regions. Paine and Vadas (1969) measured the role of predation by sea urchins on subtidal algal communities in the San Juan Islands. Using wire enclosures to exclude the urchins, they followed the pattern of algal succession for up to three years. They found that the number of species increased briefly, after which brown algae, *Laminaria* spp., dominated the algal stand.

Woodin (1972) conducted exclusion pen studies in the lower intertidal regions of the San Juan Islands. She discovered that the small mesh pens she was using became covered with a diatom layer which attracted tube building polycheates. These species of polychaetes were effectively excluded from inside

the cage. Non-tubicolus worms were found to increase in response to the reduced number of polychaete tubes in the cage sediments. She demonstrated the importance of biological interaction in determining the infaunal assemblege in soft muds.

The nature of the predator control studies is characterized by manipulation of the "keystone" predator species. The influence of this animal is so important that its removal from the community alters the understory, or subdominant species.

The role of predator in Similk Bay is shared by several species of fish (*see* Table 8.3-6) and crabs (*C. magister, C. gracilis, Oregonia gracilis,* and *Hyas lyratus*). Research on the effect of predation on the infauna was not directed toward a single "keystone species," but a species that undoubtedly contributes to the rate of predation on the infauna in Similk Bay. What might be the effect of increased predation on the benthic infauna if Dungeness crabs were attracted and concentrated in an outfall area by elevated temperatures? Or what would be the effect of the removal of all predation on benthic infauna if the major predators were excluded from the outfall area by elevated temperatures? The shortcoming in the present experimental design was that the additional effect of elevated temperatures on the composition of the infauna could not be measured, in other words, even though some predictions could be made about changes in infauna in the presence or absence of predation produced by elevated temperatures, the combined effect of the elevated temperatures on the infauna could not be incorporated into the prediction.

8.3.3 Methods

8.3.3.1 Underwater Pen Studies

A long-term series of experiments was designed for the purpose of assessing the role of predation by *C. magister* on the composition of the infauna community. The levels of crab density on given areas of bottom were controlled by means of underwater enclosures as illustrated in Fig. 8.3-1. In some cases selected numbers of crabs were held in cages while other pens were empty. Changes in the composition of infauna were estimated from core samples collected within the experimental sites.

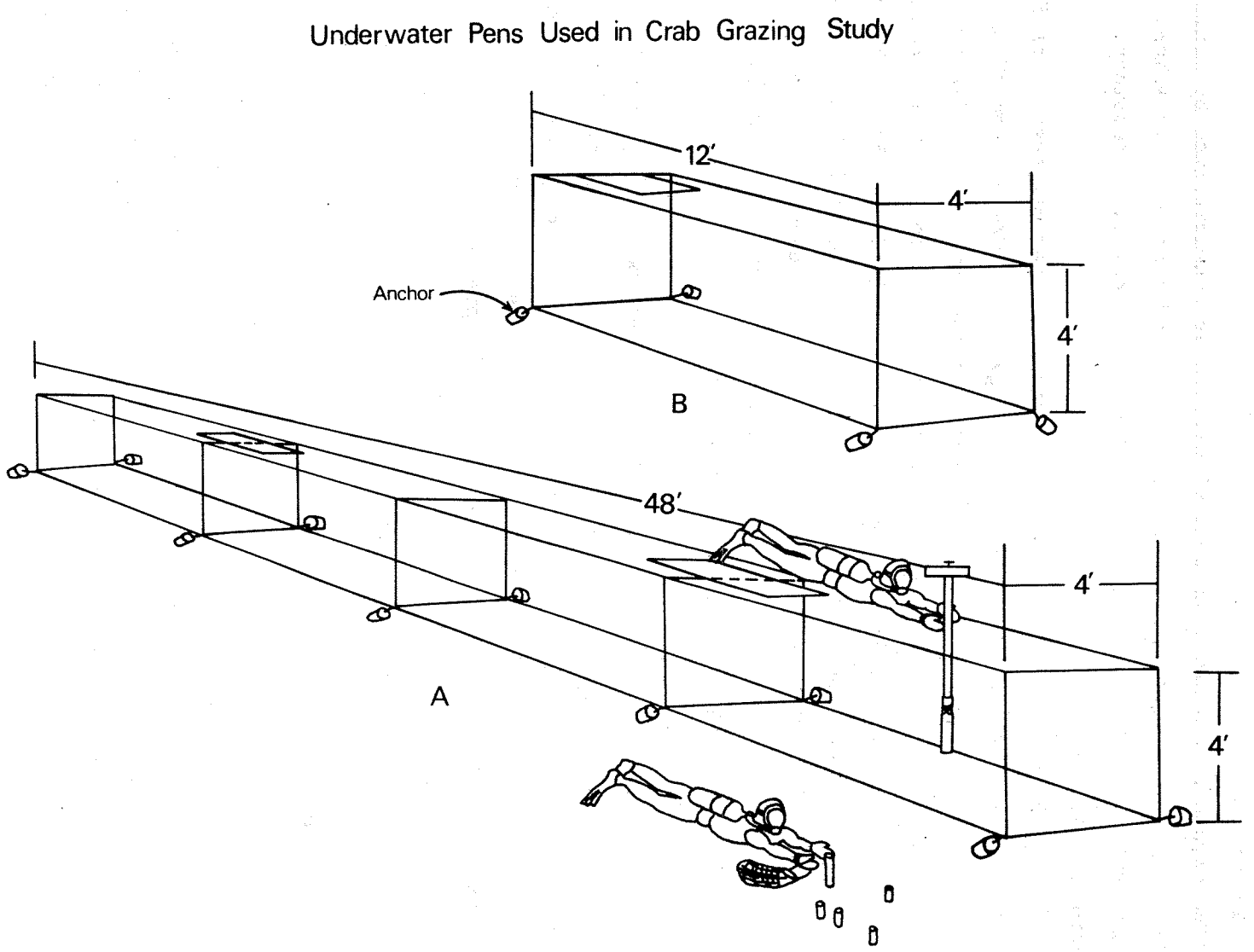


Fig. 8.3-1. A sketch diagram illustrating the underwater pens used in the crab predation experiments.

Pens of two basic designs were used to hold or exclude crabs from bottom areas. The first was constructed of 16-gauge vinyl-coated wire mesh with 1 x 2-1/4 inch (2.5 x 5.7 cm) openings. It measured 4 x 4 x 48 ft (1.2 x 1.2 x 14.6 m) and had four compartments 4 x 4 x 12 ft (1.2 x 1.2 x 3.6 m). Each compartment was equipped with an entrance in the roof made by cutting loose three sides of a square of mesh 1 ft x 1 ft (0.3 x 0.3 m). The uncut fourth side served as a hinge. The door was secured by polypropelene line. Crabs were placed in the cages through these openings in the roof. The pen was found to be less rigid than expected and a reinforcing frame of PVC pipe was lashed to the bottom edge. Cross-bracing short lengths of pipe were provided every 12 ft (3.6 m) along the length of the pen. The panels of wire were joined by clips, which were coated with vinyl touch-up paint after pen construction.

A second pen was designed in the following year. The new pen was constructed of heavier gauge and smaller mesh material (12 gauge vinyl-coated 1 x 1 inch (2.5 x 2.5 cm) mesh). Two pens were built with dimensions of 12 x 4 x 4 ft (3.6 x 1.2 x 1.2 m) and were found to be very rigid and required no additional support. The second pen was assembled in the same manner as the first pen and metal clips were vinyl coated. A hatch similar to that of the first pen was cut into the roof.

The pens were towed to their installation locations by small boat. The sides of the pens were bouyed with styrofoam blocks. The towed pens were directed by SCUBA divers swimming alongside. The pens were untied at the surface and slowly lowered to the bottom. All pen sites were within 20-25 ft (6.1-7.6 m) of water (MSL). The pens were placed lengthwise to the prevailing current direction. The locations of the pens are illustrated in Fig. 8.2-3. Since the bottom of the pens was left open, the bottom edge of the pen was pushed into the mud by SCUBA divers. At most locations it was possible to push the lower edge from 6 to 8 inches (15.2 to 20.3 cm) into the sediments. Cement anchors weighing approximately 60 lb (27 kg) were tied to all four corners of the pens. Additional anchors were placed at 12-ft (3.6 m) intervals along both sides of the longer pen. The pen locations were marked with plastic bottle floats attached to 30-40 ft (9.1-12.2 m) of line.

The experiment was partially duplicated at two locations. The long four-compartmented pen was placed on the north side of the Island in the cove in front of the on-site laboratory. The two smaller pens were placed on the south side of the Island nearly in line across the causeway from the north-side pen (Fig. 8.2-3). In the early stages of the study during the summer of 1970, it was attempted to use flatfish, *Parophrys vetulus* and *Platichthys stellatus*, in the predation experiments. High mortality and loss of fish during experiments discouraged the continuation of this study. It was decided to concentrate on the Dungeness crab as an experimental subject.

The experimental design was as follows: In the north-side pen three crabs were placed in compartment one, two crabs in compartment two, one crab in compartment three, and none in compartment four. In the south-side pens one crab was placed in one pen and no crabs were placed in the second pen. Core samples were collected routinely. Normally, when weather and boats permitted, cores were collected monthly. Ten core samples were taken from each compartment and 20 cores were taken in the close vicinity of the pen. Cores were collected from each compartment in the Similk Bay pen (Fig. 8.3-1,A) by pushing the coring device shown in Fig. 8.3-2 through a mesh in the roof of the pen. The coring tubes were 10-inch lengths of 3/4-inch, thin-wall PVC pipe. The coring tube was 3/4 inch (2.31 cm) in diameter (ID) and was normally filled with approximately 6-8 inches (15.2-20.3 cm) of sediment. Random sampling was insured by the use of the mesh squares in the roof as a grid and a random numbers table. The numbers chosen from the table dictated the location of the core sampler in the numbered mesh grid. The location of core samples taken outside the pens were randomized by eye and hence may be biased to some extent. Core samples were collected from inside the Hope Island Bay pens (Fig. 8.3-1,B) by gently turning the pen onto its side and sampling the exposed area by hand coring. Again, these samples were not truly random, but some attempt was made to approximate a random sampling procedure. The pen was then righted over the same area. The crab being used in the experiment nearly always stayed on the side of the pen during sample collection and so the same crab was retained in the experiment.

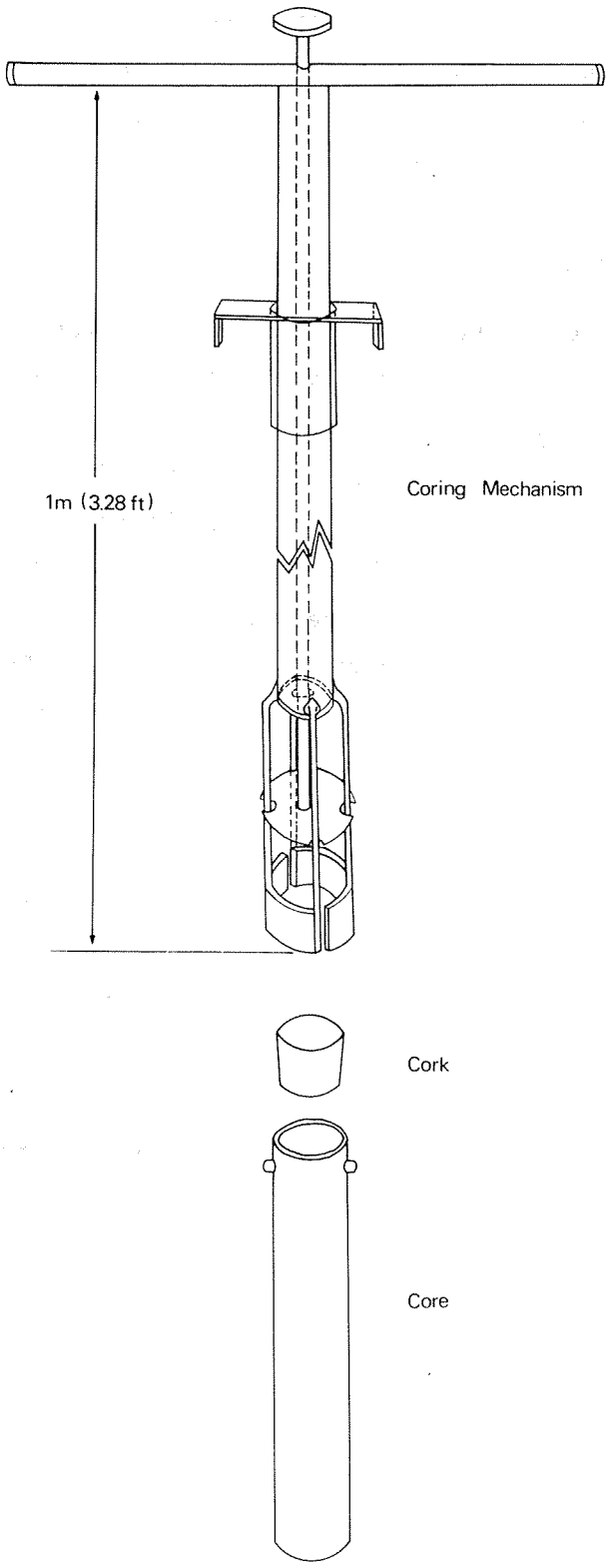


Fig. 8.3-2. An illustration of the coring device used to collect core samples inside the underwater pen.

Experiments were conducted on three separate occasions and the pens were moved for each new experiment. The anchors were removed and the pens rolled along the bottom. Relocation did not significantly change the physical conditions of the experiment.

8.3.3.2 Grab Samples

Grab samples were taken with a 1/10 m^2 Van Veen sampler at depths of 40 and 60 ft (12.2 and 18.3 m) at locations on the north and south sides of Skagit Island (Fig. 8.2-3). Five replicates were taken at each station in December 1970 and April, June, and October 1971. Limitations of time and manpower permitted analysis of only the December 1970 series of samples. Five grab samples were collected in February 1972 at the 20-ft depth (6.1 m) in the vicinity of the north-side pen experiments.

All samples were sieved through a 0.495-mm-mesh Tyler standard screen. The grab sample fractions retained by the screen were fixed in 10% Formalin buffered with calcareous material. Core samples were either processed fresh in the field or taken back to the University and frozen until analysis could be made. The sediment from the grab sample was sieved through a 1.00-mm-mesh screen before it was passed through the 0.495-mm-mesh screen for the purpose of accelerating the washing process. The results of the two screenings were later combined. The fraction of sediment from the core samples rinsed through the 0.495-mm-mesh screen was retained beneath this screen by a 0.061-mm-mesh screen. The clay was thoroughly washed from this second fraction. The portion retained on the screen was dried in sample bottles at 50 C for 24 hr, the dried residue was sprinkled into a beaker of CCl_4, and the supernantant was decanted through a Whatman No. 1 filter paper. A number of these samples were examined for Foraminifera and diatom contents.

The screened portions were sorted beneath a dissecting scope. Animals were identified to species or saved for later identification. Numbers of individuals were recorded for species and keypunched.

Taxonomy proved to be the most time-consuming portion of the analysis, as in other benthic studies. A reference collection was created by mounting the identified species in a gelatin-glycerine mixture. In some cases gammerid amphipods were stained with methyl green and dissected before

mounting. Many new and different forms were encountered and much assistance was provided by expert taxonomists in the final identifications. Some specimens were encountered so infrequently that identification was left at the generic level.

8.3.3.3 Trawling Methods

Invertebrates taken in otter trawling operations described in section 9.0 were identified and recorded to the lowest possible taxon aboard ship. Unusual or unidentified forms were preserved in 10% Formalin and labeled for later examination. Invertebrates collected in trawl samples from August 1970 to October 1971 were casually recorded, therefore, the data reported for this period are incomplete. In subsequent trawling, the invertebrate samples were rigorously sorted and counted. Wet weights in grams were recorded for each species or recognized taxonomic division. Where the total weight of a species was less than 2 or 3 g the weight was approximated.

The number and wet weight of invertebrate species were recorded from trynet samples beginning in October 1971. Replicate samples were collected from the shallow-water stations in Similk and Skagit Bays and Ala Spit (*see* Fig. 9-1). The trynet was fished as described in section 9.0. The samples were processed in the on-site laboratory. Weight was measured by means of the laboratory scales, therefore the measurements were more accurate than those taken by otter trawl catches in the field.

8.3.3.4 Collection and Processing of Predator Stomach Samples

Stomach samples were collected from a total of 123 flatfish captured by trynet in a series of six trawls, three in Similk Bay and three in Skagit Bay, in June 1971. The length of each specimen and station and date of sampling were recorded on a label included with the stomach. The stomachs were removed immediately after sampling and preserved in 10% buffered Formalin. Prey items were identified under dissecting microscope to the lowest possible taxon.

Fifty stomach samples were collected from Dungeness crabs trapped in Similk Bay during the period July 1971 to September 1971. The crabs had

been in the traps less than 24 hr. A portion of the stomachs were examined immediately after removal, and the majority were preserved in 10% Formalin for later examination. All prey items were identified to the lowest possible taxon.

8.3.4 Data Analysis

8.3.4.1 Diversity Indices

Analysis of the core samples was performed on the CDC 3600 computer in the University of Washington computer laboratory. Species counts from each sample were coded with appropriate sample identification and stored on magnetic tape. A Fortran program was written for computation of the various diversity indices, concordance statistic, and mean, standard deviation, and range for each species by sampling occasion. The diversity indices were computed according to the following formula:

$$H = -\Sigma \frac{n_i}{N} \ell n \frac{n_i}{N} \text{ (Pielou, 1966)}$$

$$H(\text{scaled}) = \frac{H-A}{\ell nS-A} \text{ (Fager, 1972)}$$

$$D = \frac{S-1}{\ell nN} \text{ (Margalef, 1968)}$$

$$NM = \frac{N(S+1)}{2} - \Sigma R_i n_i \text{ (Fager, 1972)}$$

$$NM(\text{scaled}) = 1 - \frac{N(S+1) - 2\,\Sigma R_i n_i}{(N-S)\,(S-1)}$$

where: n_i = number of the i^{th} species

$N = \Sigma n_i$

S = number of species

R_i = rank of the i^{th} species (1 is highest rank)

$$A = \ell nN - \frac{N - S + 1}{N} \ell n(N - S + 1)$$

A concordance analysis was conducted of species ranked within each core sample and compared within treatment group. The "W" statistic was computed according to the following equation:

$$W = \frac{12S}{M^2 n(n^2 - 1) - M \Sigma t(t^2 - 1)}$$

where: M = number of samples,
n = number of species,
t = number of ties for the tied ranks, and
S = the sum of the squares of the deviations of the summed ranks from their means.

8.3.4.2 Factor Analysis

Factor analysis was performed on all of the samples according to the techniques described by Lie and Kelly (1970) and based on the statistical approach reviewed by Seal (1964).

Burt and Banks (1947) described factor analysis as a "statistical technique for reducing a large number of correlated variables to terms of a small number of uncorrelated variables. The correlated variables consist usually of measurements for observable traits; the uncorrelated variables (called "factors") are abstract hypothetical components." As pointed out by Seal (1964), the technique is similar to principle component analysis, with one important difference, "only a portion of the variances or the unities in the diagonal of the estimated variance-covariance or correlation matrix, respectively, is regarded as due to the $m < p$ transformed variates." In other words, the mathematical model does not imply that each of the p original variates is analyzable into m factors, i.e., $m = p$; it allows for a residual component of variance in the matrix. In the present study this residual component might be composed of either sampling error or some other unmeasured variate.

Factor analysis has been applied rarely in the solution of biological problems. Recent computer programming has removed the tedious hand calculations of the technique and made it more readily applicable. Seal (1964), in his review of multivariable analyses for biology, cited all the applications of factor analysis at that time in the solution of biological problems. Of the 15 studies he cited, 10 studies were concerned with taxonomic analysis of morphological characters, two with

plant community analysis, two with insect behavior, and one was not discussed More recent examples of multivariate analyses of marine benthic communities include Cassie and Michael's (1968) study of a New Zealand mudflat and Lie and Kelley's (1970) study of the benthic fauna along the Washington coast.

The present study is based on the mathematical methods developed by Dr. James Kelley of the University of Washington Oceanography Department. The techniques were programmed in a FORTRAN program, FORMAN, for the CDC 3600. Many of the mathematical manipulations and sequences are described by Imbrie and Van Andel (1964) in their study of data on heavy minerals from the Gulf of California. Imbrie and Van Andel's (1964) description of the computer operations will be briefly summarized below. For further details the reader is referred to Seal (1964) and Imbrie and Van Andel (1964).

The FORMAN program used in the present study incorporates two statistical techniques, vector analysis and factor analysis. Factor analysis operates on a matrix of transformed data. The raw data are transformed into one of two modes used in the construction of the matrix to be factored. The R-mode treats the data in a species-by-station aspect, in which the matrix is filled with correlation coefficients among species by stations. The Q-mode treats the input data in a station-by-species aspect. Although a correlation coefficient could be calculated for each station, the reduction of the species counts to a single mean for each station would sacrifice valuable information and leave only a statistic on the total number of animals at the stations. The use of vector analysis permits the retention of information on species composition for the station-by-species analysis mode.

The computer operation begins with the conversion of the species composition and abundance of each sample into a sample vector. This operation is is shown diagrammatically for a three-species coordinate system in Fig. 8.3-3. As discussed by Inbrie and Van Andel (1964), the concept of a station vector in a large coordinate system becomes theoretical, since its solution is algebraic and not geometric. In the present study a 100-species coordinate system was used in the computation of sample vectors. The choice of the number of coordinates to be used in the vector analysis must be made by the investigator usually on the basis of an *a priori* idea of the problem.

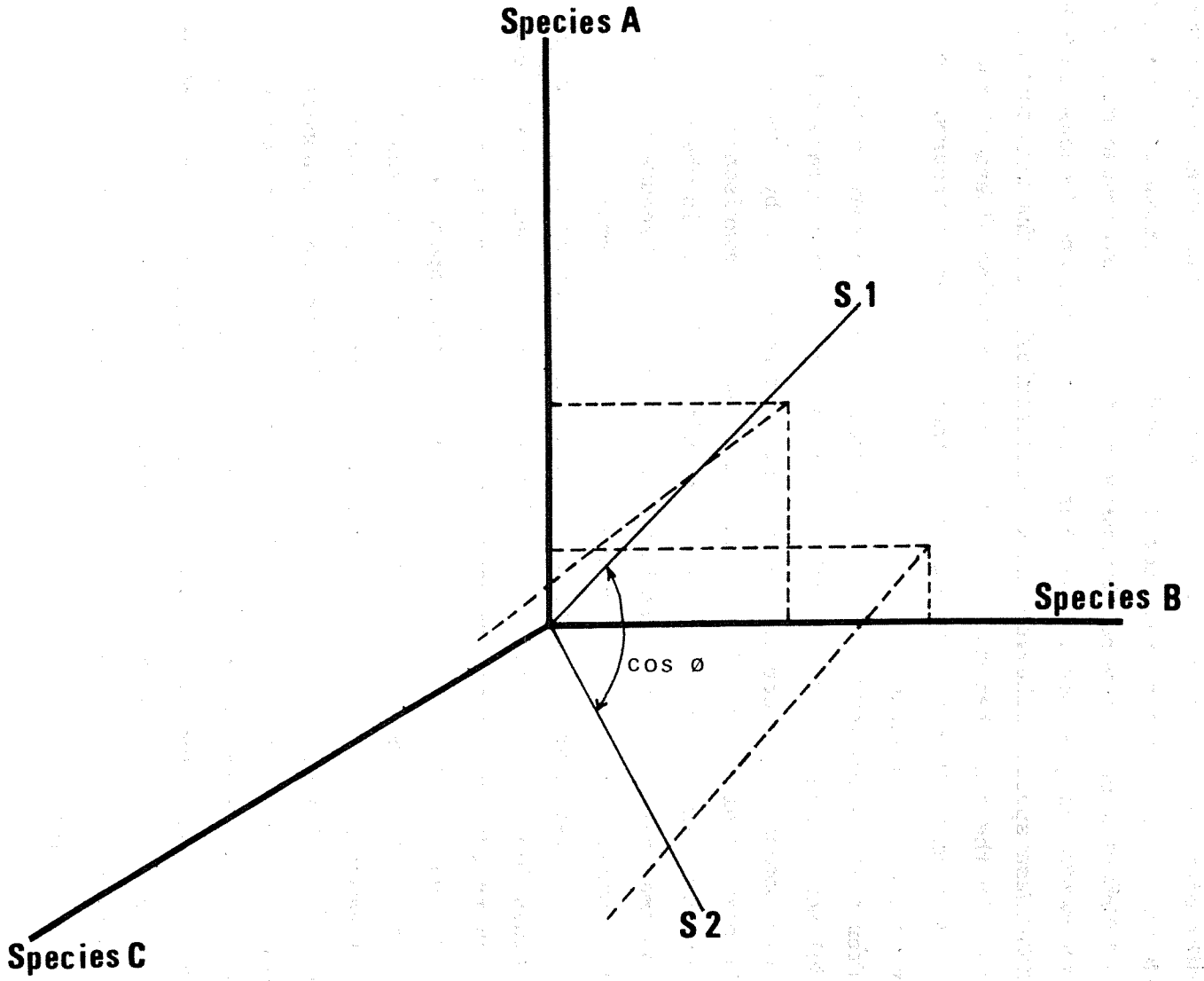


Fig. 8.3-3. Sketch diagram illustrating the mathematical treatment of input data points by the Forman factor analysis program. Species A, B, and C are the arbitrary first three species in the sample. They serve as coordinates in the construction of the sample vectors (S1 and S2).

The choice of the 100 species for the present analysis was based on a number of input variables, species, that could be handled in the computer program. Rare or infrequent species were eliminated on the basis that several other authors (Imbrie and Van Andel, 1964; Seal, 1964; Cassie and Michael, 1968) felt that these species make very little statistical contribution to the analysis. On the other hand, since there were no *a priori* ideas of the community structures and boundaries, an attempt was made to incorporate as many species as possible.

After the computation of station vectors, the cosine theta value is calculated. The cosine theta value is a statistic that expresses the degree of commonality or correlation between sample vectors by the degree of angle between all pairs of samples. It allows the comparison of sample vectors, in contrast to the correlation coefficient in the R-mode, which compares sample means. Sample means were not used because of the loss of information on species composition as discussed earlier.

The station-by-station matrix is filled with the calculated cosine theta values for all possible pairs of samples. In the present study each sample was treated as a separate station. The cosine theta matrix contained 100 samples by 100 samples. The matrix is then operated on by the factor analysis routine. The matrix is analyzed for a factor that minimizes the variance of the cosine theta values about the factor by a least-squares fit. This initial factor is designated factor one and appears diagrammatically as P1 in Fig. 8.3-4. All of the cosine theta values surrounding this point are collapsed along the axis of factor one. The projection of the cosine theta values onto the plane removes that variance explained by factor one from the total matrix variance. As shown in Fig. 8.3-4, about 30 per cent of the total variance in the cosine theta matrix is explained by factor one.

8.3.5 Results

8.3.5.1 Invertebrate Collection

An infauna reference collection was the first concern in the subtidal sampling program. Taxonomy and identification consumed enormous amounts of time. The small fauna averaged 0.2 inch (5 mm) and were little known or

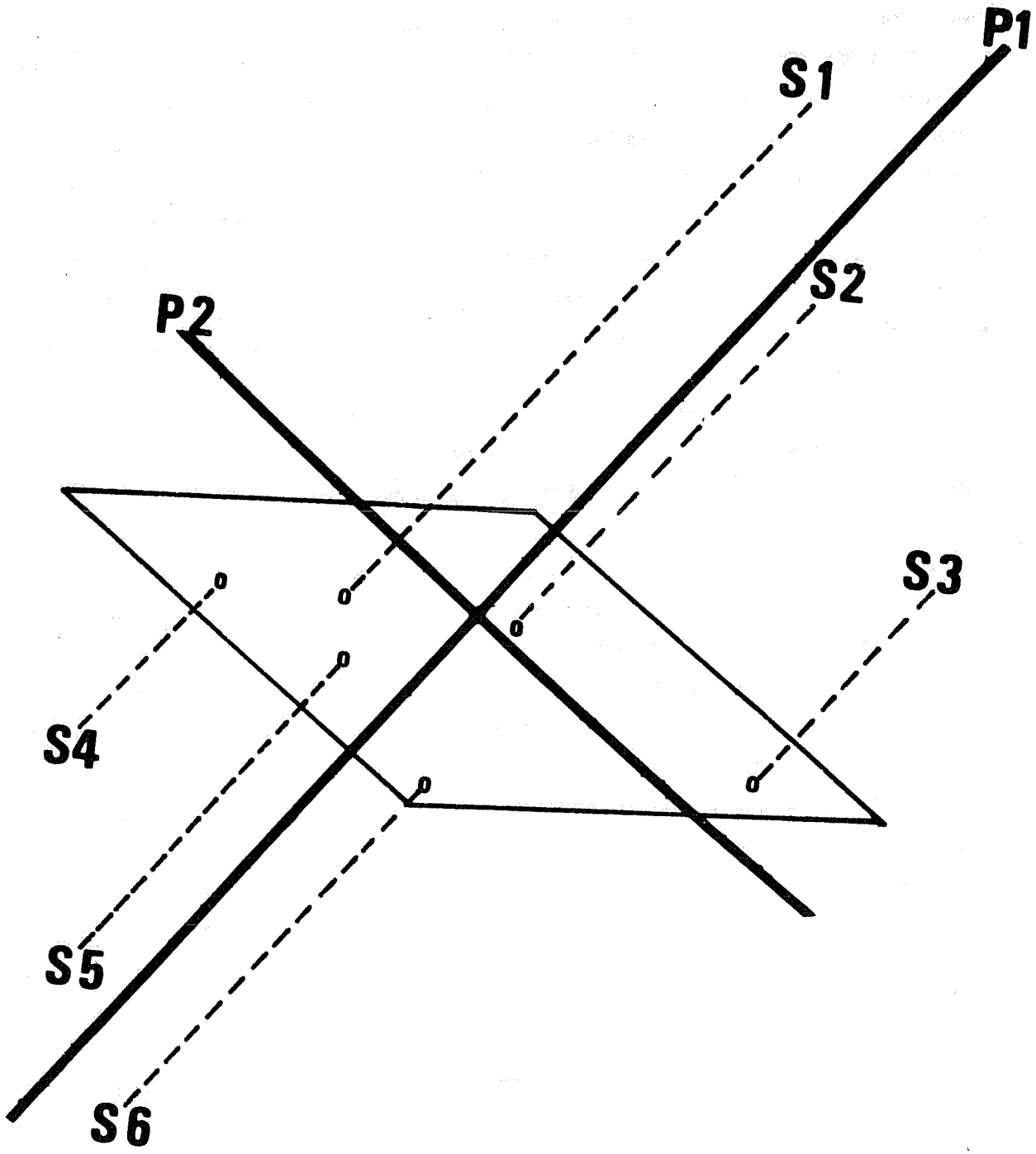


Fig. 8.3-4. Sketch diagram of core sample vector points, S1, 2, 3, 4, 5, and 6 as derived in Fig. 8.3-3, fitted to factor P1 by least squares. Data points are then projected onto a plane, orthogonal to P1, and fitted by least squares to factor P2.

described for this area. Lie (1968) made the first significant contribution to the description of benthic infauna in Puget Sound and his work provided a valuable background and reference for the present study, but many new forms and several new species were encountered.

Most specimens could be identified approximately to genus by the use of existing keys for West Coast fauna, but below the generic level the problems increased. The emphasis in early and positive identification was placed on the most numerous of the specimens collected so that the analysis would be expedited. It was thus possible to sort the samples by accurate identification and by counts of the majority of the animals in the cores. This method failed with the Isaeidae amphipods: *Photis* sp. was confused with *Ericthonius* sp., a very similar genus, in the early core analyses. Because of some inaccuracies in identification, it was necessary to lump questionable material into larger categories for the initial period of analysis. Infrequently encountered unknowns were removed from the sample, labeled, and stored for future identifications.

Once the cores had been analyzed, identification of some of the infrequent specimens was begun. In addition, the identification of the common specimens was rechecked. Problem specimens for which species nomenclature was impossible to determine or was in doubt were assembled in taxonomic groups. A number of taxonomic experts were contacted for assistance in the groups of their speciality. The lack of expert assistance is becoming a serious stumbling block to ecological studies; because of the burgeoning of quickly founded and funded environmental organizations, there is great demand for the talents of the few taxonomists available.

Some taxonomists have established a set of criteria that the specimens sent them must meet before they will examine them. Dr. Barnard (1972, personal communication) believes that the responsibility rests on the collector to sort and identify his own material as far as possible. Because of the scarcity of taxonomists, a degree of exactness must be sacrificed until the time comes when more taxonomists are available to share the work or until massive assistance can be provided for this endeavor.

These limitations and points of view apply to the following list (Table 8.3-1) of the species of infauna collected from the the subtidal region of Kiket Island. Included in a separate section in the list are the

Table 8.3-1. Check list of benthic invertebrate species collected in core samples during the period of January 1970 to June 1972. The relative abundance of each species is noted as A = abundant, C = common, S = scarce, and R = rare. Included are invertebrate species caught by trawling

		Occurrence
Sipunculida		
Golfingia pugettensis FISHER	Fisher (1952)	R
Priapulida		
Priapulus sp. (Larvae)		S
Nemertini		
Nemertini idet.		R
Annelida		
Polychaeta		
Polynoidae		
Atinoella macrolepida MOORE	Berkeley and Berkeley (1948)	R
Eunoë sp.		R
Harmothoë imbricata LINNÉ	Berkeley and Berkeley (1948)	R
Malmgrenia lunulata DELLE CHIAJE	Pettibone (1953)	R
Sigalionidae		
Pholoë minuta FABRICIUS	Pettibone (1953)	S
Sthenelais articulata KINBERG	Berkeley and Berkeley (1948)	S
Phyllodocidae		
Eteone sp.		S
Eulalai sp.		S
Phyllodoce williamsi HARTMAN	Berkeley and Berkeley (1948)	S
Syllidae		
Autolytus sp.		C
Exogone lourei BERKELEY	Berkeley and Berkeley (1948)	C
Syllis heterochaeta MOORE	Berkeley and Berkeley (1948)	C
Syllis sp.		C
Nereidae		
Micronereis nanaimoensis BERKELEY	Berkeley and Berkeley (1948)	S
Nereis sp.		R
Nephtyidae		
Nepthys caecoides HARTMAN	Anon (1969)	C
Nepthys punctata HARTMAN	Anon (1969)	S
Sphaerodoridae		
Sphaerodoridium sphaerulifer MOORE	Banse and Hobson (in press)	C
Glyceridae		
Glycera capitata OERSTED	Anon (1969)	S
Glycera nana JOHNSON	Anon (1969)	C

Table 8.3-1. Check list of benthic invertebrate species collected in core samples during the period of January 1970 to June 1972. The relative abundance of each species is noted as A = abundant, C = common, S = scarce, and R = rare. Included are invertebrate species caught by trawling - continued

		Occurrence
Goniadidae		
Glycinde armigera MOORE	Anon (1969)	S
Glycinde sp.		S
Lumbrineridae		
Lumbrineris bicirrata TREADWELL	Berkeley and Berkeley (1948)	C
Lumbrineris luti BERKELEY	Anon (1969)	A
Lumbrineris sp.		C
Orbiniidae		
Haploscoloplos pugettensis PETTIBONE	Berkeley and Berkeley (1952)	R
Spionidae		
Prionospio malmgreni CLAPARÈDE	Banse and Hobson (in press)	S
Spiophanes sp.		R
Cirratulidae		
Tharyx sp.		R
Opheliidae		
Ammotrypane aulogaster RATHKE	Anon (1969)	C
Armandia brevis MOORE	Berkeley and Berkeley (1941)	C
Sternaspidae		
Sternaspis fosser STIMPSON	Berkeley and Berkeley (1952)	S
Capitellidae		
Capitellidae sp.		S
Maldanidae		
Axiothella rubrocincta JOHNSON	Anon (1969)	S
Clymenura columbiana BERKELEY	Berkeley and Berkeley (1952)	S
Euclymene zonalis VERRILL	Berkeley and Berkeley (1952)	R
Nicomache lumbricalis FABRICUS	Anon (1969)	S
Praxillela gracilis SARS	Anon (1969)	A
Rhodine bitorquata MOORE	Anon (1969)	C
Ampharetidae		
Ampharete sp.		S
Terebellidae		
Pista sp.		R
Trichobranchidae		
Terebellides stroemi SARS	Berkeley and Berkeley (1948)	A

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		Occurrence
Crustacea		
Ostracoda		
Euphilomedes carcharodonta SMITH	Smith (1952)	A
Euphilomedes producta POULSEN	Poulsen (1962)	A
Leguminocythereis cf. *L. filoplumosa* LUCAS	(Benson, pers. comm.)	C
Acanthocythereis dunelimenis	(Benson, pers. comm.)	S
Tetragonodon (mayeri)	n.sp. to be described by L. S. Kornicker of the Nat. Mus. Nat. Hist.	
Cylindrolebris mariae BAIRD	Judy (1907)	
Copepoda		
Harpacticoidea		
Diosaccus spinatus CAMPBELL	Lang (1948)	C
Harpacticus uriremis KROYER	Lang (1948)	S
Amphipoda		
Gammeridae		
Allorchestes sp.		S
Ampelisca macrocephala LILLJEBORG	Barnard (1960b)	S
Ampelisca shoemakeri	Barnard (1960b)	S
Ampelisca sp.		S
Amphithoe lacertosa BATE	Barnard (1954)	S
Dulichia sp. n.sp.		
Harpiniopsis fulgens BARNARD	Barnard (1960a)	R
Heterophoxus oculatus HOLMES	Barnard (1960a)	A
Westwoodilla caecula BATE	Mills (1962)	S
Melita desdichada BARNARD	Barnard (1960b)	S
Metopella sp.		S
Monoculoides cf. *Crassirostris*	Barnard (1962c)	S
Orchomene anaquela BARNARD	Barnard (1964)	C
Paraphoxus cognatus BARNARD	Barnard (1960b)	R
Paraphoxus oculatus SARS	Barnard (1960b)	C
Photis bifurcata BARNARD	Barnard (1962a)	C
Photis brevipes SHOEMAKER	Barnard (1962a)	C
Photis lacia BARNARD	Barnard (1962a)	A
Phoxocephalus sp.		R
Pleusymytes n.sp. (Barnard, pers. comm.)		C
Problisca sp.		S
Protomedia articulata BARNARD	Barnard (1962a)	A
Protomedia zotea BARNARD	Barnard (1962a)	C
Synchelidium shoemakeri MILLS	Mills (1962)	R

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		Occurrence
Caprellidae		
Caprella irregularis SARS	Anon (1969)	
Tritella sp.		
Isopoda		
Rocinela belliceps STIMPSON	Hatch (1947)	R
Synidothea angulata BENEDICT	Hatch (1947)	
Synidothea sp.		
Munna kroyeri GOODSIR	Hatch (1947)	
Haliophasma germinata MENZIES AND BARNARD	Menzies and Barnard (1959)	
Limnoria lignorum RATHKE	Hatch (1947)	
Bopyroid (from E. carcharodonta)		C
Tanaidacea		
Leptochelia dubia KROGER	Hatch (1947)	C
Leptognathia longiremsis LILLJEBORG	Hatch (1947)	C
Cumacea		
Diastylis pellucida HART	Lomakina (1958)	S
Diastylis alaskensis CALMAN	Lomakina (1958)	R
Eudorella pacifica HART	Lomakina (1958)	A
Eudorella tridentata HART	Hart (1930)	S
Lamprops carinata HART	Lomakina (1958)	R
Leucon sp.		R
Leptostraca		
Epinebalia pugettensis CLARK	Clark (1932)	R
Anomura		
Callianassa sp. juv.		R
Pagurus sp. juv.		R
Brachyura		
Pinnixia schmitti RATHBUN	Rathbun (1917)	R
Pinnixia occidentalis RATHBUN	Rathbun (1917)	R
Lophopanopeus bellus STIMPSON	Rathbun (1930)	R
Pycnogonida		
Nymphon sp.		S
Achelia nudiuscula HALL	Light (1970)	S
Mollusca		
Lamellibranchia		
Parvalucina tenuisculpta CARPENTER	Oldroyd (1924)	S
Axinopsida sericata CARPENTER	Dall (1901)	C

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		Occurrence
Clinocardium nuttalli CONRAD	Oldroyd (1924)	C
Protothaca staminea CONRAD	Oldroyd (1924)	C
Macoma alaskana DALL	Oldroyd (1924)	S
Macoma carlottensis WHITEAVES	Grant and Gale (1931)	S
Macoma spp.		S
Tellina buttoni DALL	Oldroyd (1924)	S
Solen sicarius GOULD	Oldroyd (1924)	R
Nucula sp.		S
Nuculana minuta FABRICIUS	Gould (1850)	R
Nuculana hamata CARPENTER	Oldroyd (1924)	S
Yoldia scissurata DALL	Oldroyd (1924)	R
Yoldia ensifera DALL	Oldroyd (1924)	C
Transenella tantilla GOULD	Oldroyd (1924)	R
Glycymeris subobsoleta CARPENTER	Oldroyd (1924)	S
Crenella sp.		R
Musculus sp.		R
Kellia suborbicularis MONTAGU	Oldroyd (1924)	S
Mysella sp.		C
Mya sp.		R
Pandora bilirata CARPENTER	Oldroyd (1924)	C
Lyonsia pugetensis DALL	Oldroyd (1924)	R
Thyasira gouldii PHILLIPPI	Oldroyd (1924)	S
Lamellibranchia indet.		
Gastropoda		
Calyptraea fastigiata GOULD	Oldroyd (1924)	R
Alvania sp.		A
Odostomia spp.	Oldroyd (1924)	C
Polinices pallida BRODERIP AND SOWERBY	Anon (1969)	S
Amphissa columbiana DALL	Anon (1969)	S
Trophon beringi DALL	Oldroyd (1924)	R
Turbonilla sp.		R
Cadulus stearnsii PILSBRY AND SHARP	Oldroyd (1924)	R
Echinodermata		
Ophuiroidea		
Amphiodia urtica LYMAN	Kyte (1969)	C
Diamphiodia occidentalis LYMAN	Kyte (1969)	R
Amphipholis squamata DELLE CHIAJE	Dyakonou (1954)	R
Holothuroidea		
Leptosynapta clarki HEDING	Heding (1928)	R

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		Occurrence
Asteroidea		
Leptasterias sp.		R
TRAWL CAUGHT SPECIES		
Coelenterata		
Anthozoa		
Epiactis prolifera VERRILL	Anon. (1969)	R
Metridium sp.		C
Tealia sp.		S
Leioptilus querneyi GRAY	Kükenthal (1915)	S
Annelida		
Errantia		
Aphrodite japonica MARENZELLER	Anon. (1969)	S
Anthopoda		
Crustacea		
Thoracica		
Balanus nubilus DARWIN	Anon. (1969)	S
Isopoda		
Argeia pugettensis DANA	Hatch (1969)	C
Isopoda idet.		S
Decapoda		
Munida quadrispina BENEDICT	Schmitt (1921)	R
Crago alaskensis RATHBUN	Schmitt (1921)	R
Crago franciscorum STIMPSON	Schmitt (1921)	A
Pandalus danae STIMPSON	Schmitt (1921)	A
Pandalus hypsinotus BRANDT	Anon. (1969)	C
Pandalus platycerous BRANDT	Schmitt (1921)	C
Pandalus goniurus STIMPSON	Anon. (1969)	S
Pandalus borealis KRÖYER	Anon. (1969)	R
Pandalopsis dispar RATHBUN	Anon. (1969)	R
Heptacarpus kincaidi RATHBUN	Anon. (1969)	C
Lebbeus greenlandicus FABRICIUS	Anon. (1969)	C
Paracrangon echinata DANA	Schmitt (1921)	A
Spirontocaris lamellicornis DANA	Schmitt (1921)	A
Spirontocaris spp.		
Cancer magister DANA	Schmitt (1921)	
Cancer productus RANDALL	Schmitt (1921)	
Cancer gracilis DANA	Schmitt (1921)	A
Cancer oregonensis DANA	Schmitt (1921)	C
Lophopanopeus belli STIMPSON	Schmitt (1921)	S
Chinoecetes bairdi RATHBUN	Anon. (1969)	R

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		Occurrence
Hyas lyratus DANA	Anon. (1969)	A
Oregonia gracilis DANA	Anon. (1969)	A
Pugettia gracilis DANA	Schmitt (1921)	A
Pugettia producta RANDALL	Anon. (1969)	S
Chorilia longipes DANA	Anon. (1969)	C
Telemessus cheiragonus TILESIUS	Anon. (1969)	S
Mollusca		
Amphineura		
Cryptochiton stelleri MIDDENDORFF	Anon. (1969)	R
Pelecypoda		
Pectin caurinus GOULD	Anon. (1969)	S
Pectin sp.		S
Polinices sp. (egg cases)		C
Gastropoda		
Bullaria gouldiana		A
Ceplapoda		
Rossea pacifica		
Loligo opalescens		
Echinodermata		
Asteroidea		
Henrica leviuscula STIMPSON	Anon. (1969)	C
Patiria miniata BRANDT	Anon. (1969)	S
Crossaster popposus sp.		S
Leptasterias sp.		A
Pisaster ochraceus BRANDT	Anon. (1969)	A
Pycnopodia helianthoides BRANDT	Anon. (1969)	S
Holothuroidea		
Stichopus californicus STIMPSON	Anon. (1969)	
Cucumaria spp.		
Echinoidea		
Stronylocentrotus drobachiensis MULLER	Anon. (1969)	R

epifaunal invertebrates not collected in cores or grab samples but sampled in the trynet or otter trawl.

8.3.5.2 Numerically Abundant Species

The most abundant organisms of the infauna collected at the 20-ft (6.1 m) stations were the clams, *Transenella tantilla*, *Euphilomedes carcharodonta*, and *Euphilomedes producta*. These three species made up 51 per cent of the total number of individuals collected in core samples. Other slightly less common species included the amphipods, *Photis lacia*, *Heterophoxus oculatus*, and *Protomedia* sp. The dominant polychaete worms were *Syllis heterochaeta*, *Terebellides stroemi*, and *Praxiella gracilis*.

Length frequency analysis of the sample of *Euphilomedes carcharodonta* and *Euphilomedes producta* are presented in Fig. 8.3-5 and Fig. 8.3-6 respectively. The modes above 1.6 mm compared favorably with those reported by Lie (1968) from other stations in Puget Sound, but those below 1.3 mm represent unreported sizes. These lower modes are probably the result of using a smaller mesh screen, 0.495 mm, than Lie did, 1.00 mm. Undoubtedly the modes below 1.00 mm are the result of differences in screen size.

The number and length of pregnant ostracods are also included in Fig. 8.3-4. Female *E. carcharodonta* had an average of 15.7 larvae/individual. Pregnant *E. producta* averaged 12.2 larvae/individual. Of the adult forms of *E. carcharodonta*, 3.1 per cent were infested with a cryptoniscid isopod. The parasite is believed to be a new species and is currently being examined by Dr. Lung, University of Oslo. The female parasite occupies the brood chamber, thus its presence prevents any brooding of young and effectively eliminates the infected female's reproductive potential. No specimens of this parasite were discovered in *E. producta*. Since *E. carcharodonta* and *E. producta* were found in nearly equal numbers in the core samples, it may be that the parasite allows the two species to exist sympatrically.

Length frequency analysis of *Transenella tantilla* during the month of June 1972 showed a single age class mode. The length frequencies are illustrated graphically in Fig. 8.3-7. This species of clam broods its young and releases them at a size of approximately 0.5 mm. Very few of these young clams were retained in the sieving. The dominant peak in the

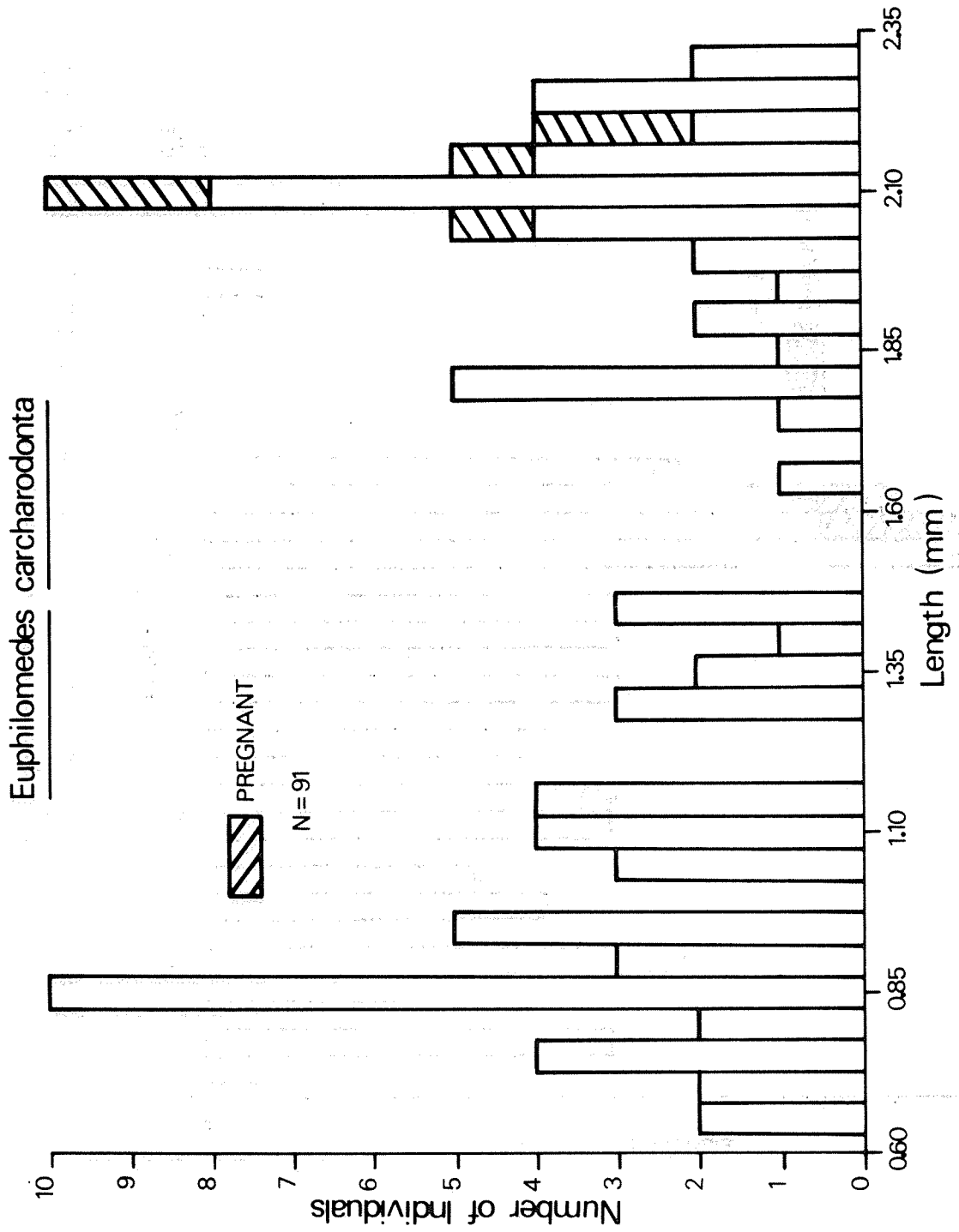

Fig. 8.3-5. Length frequency diagram of *Euphilomedes carchiarodonta* collected in Similk Bay in a number of core samples during the period of June 1971 to June 1972. The occurrence of pregnant females is included.

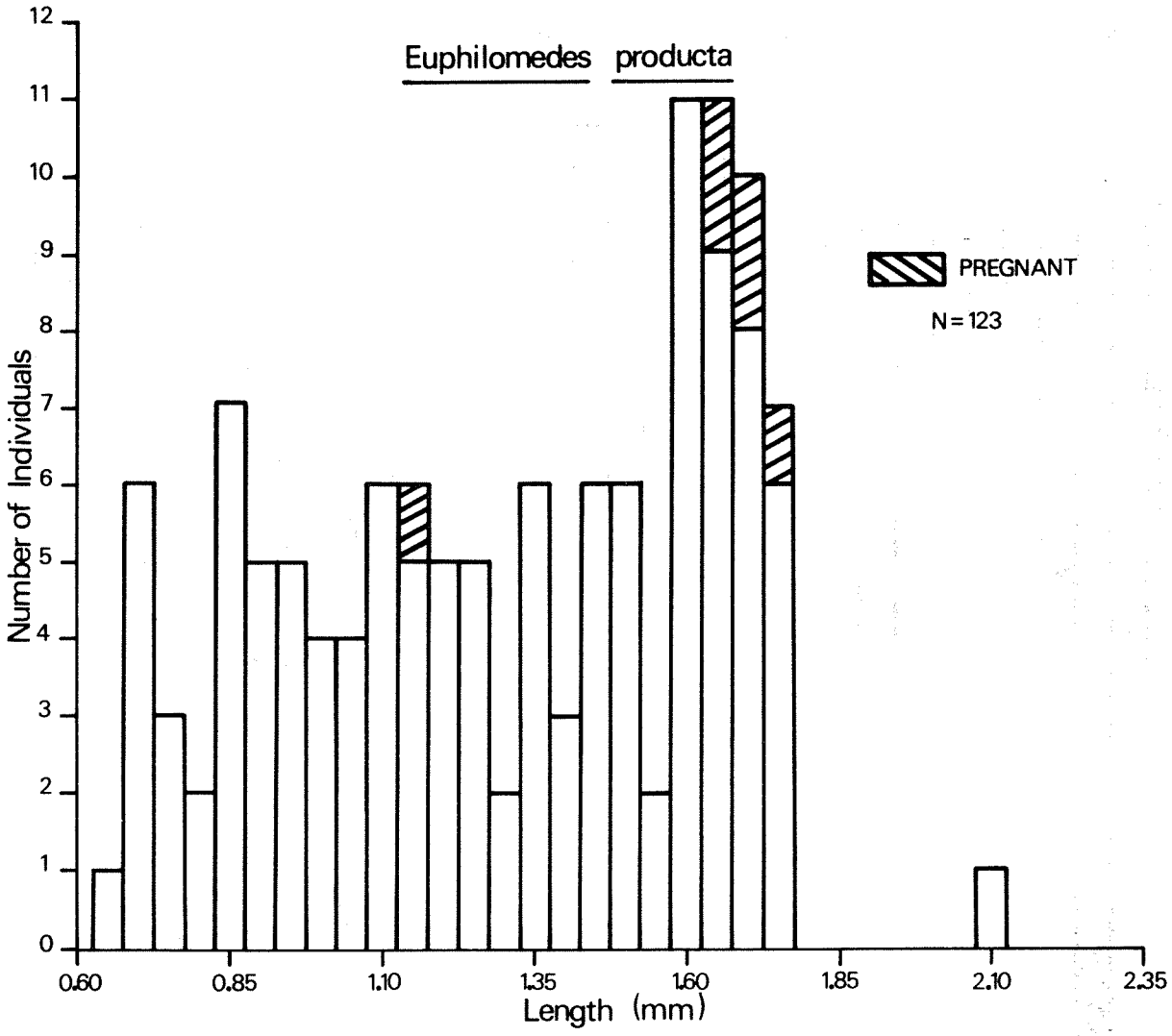

Fig. 8.3-6. Length frequency diagram of *Euphilomedes producta* collected in a number of Similk Bay core samples during the period of June 1971 to June 1972. The occurrence of pregnant females is included.

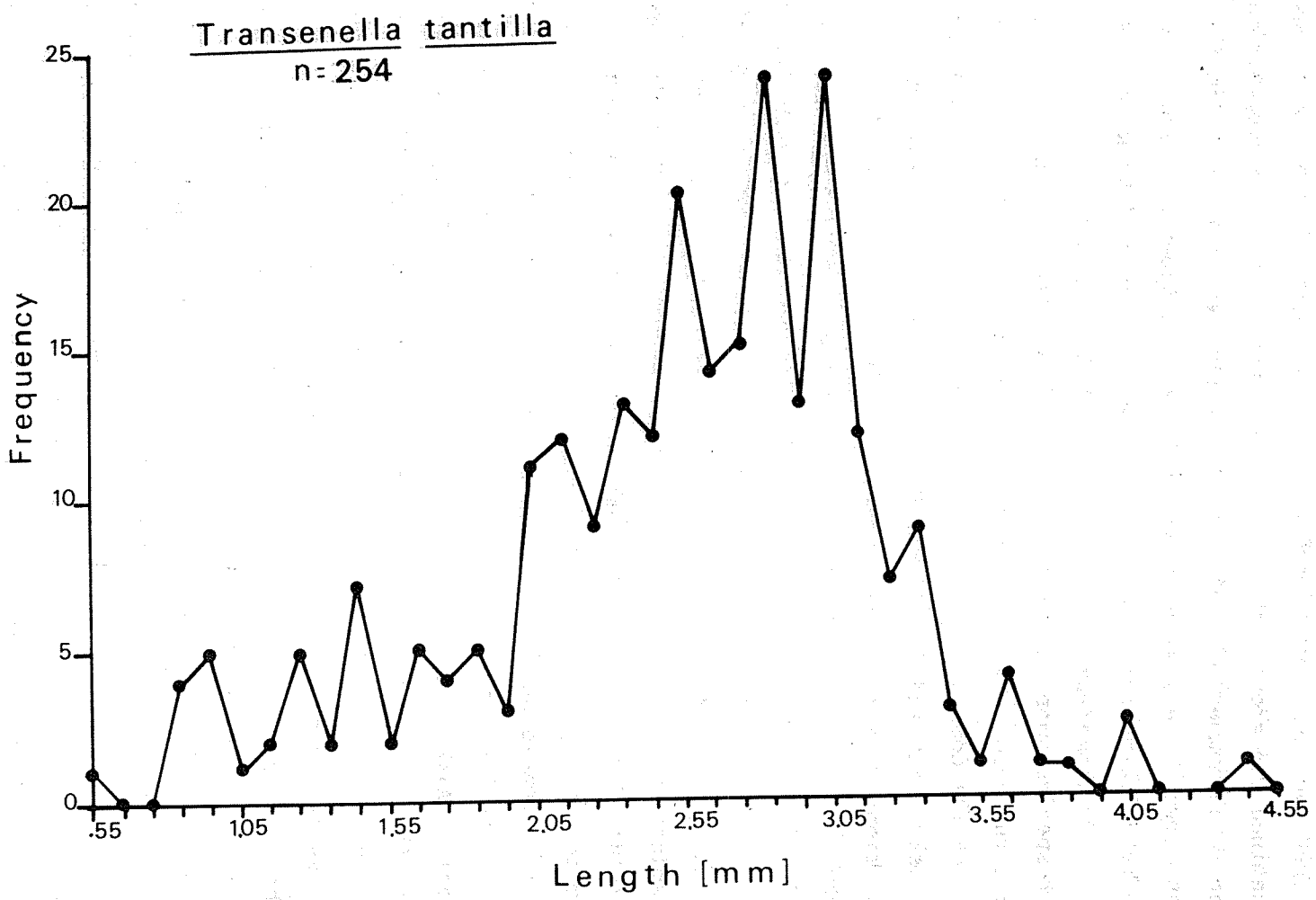

Fig. 8.3-7. Length frequency diagram of *Transenella tantilla* collected in a number of Similk Bay core samples during the period of June 1971 to June 1972.

length frequency curve may represent the one-year-old age class. Specimens were examined for growth annuli, but the annuli proved unrecognizable.

The total number of each species of invertebrate caught in the otter trawl and trynet are listed by sampling date in Appendix Table 8.A. The invertebrate epifauna collected in trawl samples was dominated by the crustaceans. *C. franciscorum* (37% of total invertebrate catch) was the numerically dominant species among the total catch for all stations and all gears. On occasion, the holothurian, *Stichopus californicus* (6.3% of total invertebrate catch), was the dominant invertebrate by weight at the deep trawl stations in Hope Island Bay and Skagit Bay-West. Normally, the species at the deep trawl stations were dominated numerically by *Pandalus danae* (21.4% of total invertebrate catch). Other less common species included *Spirontocaris kincaidi* (2.3%), *Spirontocaris lamellicornis* (1.1%), and *Pandalus hypsinotus* (0.9%), Three species of crabs, *Hyas lyratus* (1.9%), *Oregonia gracilis* (3.7%), and *Cancer gracilis* (1.2%), were also common at these stations.

Examination of the catch of *P. danae*, showed that they were predominantly female (72%). Ovigerous females were commonly encountered from November to January. There was a slight trend for the catch of this species to increase during the fall and winter months; however, the fluctuations were so large throughout the year that no definite pattern was distingushable. Algal detritus frequently caused the cod end of the trawl to clog, and the effect undoubtedly increased the efficiency of the trawl on small invertebrates, i.e., shrimp, crabs, etc. A large portion of the invertebrates caught and recorded would normally pass through the trawl cod end. The results are semiquantitative but might serve as some future index to results collected in the same manner.

Crago franciscorum was the most abundant invertebrate in the samples collected by trynet at the shallow station, constituting an average of 89 per cent of the total number of invertebrates caught per tow. The bubble snail, *Bullaria gouldiana* (4.6%), was frequently very common in the shallow water trynet samples, along with several species of spirontocarid shrimp.

8.3.5.3 Densities of Infauna

8.3.5.3.1 Meiofauna. The numbers of individuals per square meter found in grab samples are listed in Table 8.3-2. In samples from both Skagit and Similk Bays, the mean density decreased with depth. The shallow 20-ft station (16.1 m) in Similk Bay had a higher standing crop than the 40-ft (12.2 m) station in Skagit Bay. An analysis of variance performed on the number of individuals per sample showed no significant difference in the densities from all five locations. The degree of variance within station samples was very large.

The overall mean density of individuals per core sample taken in the vicinity of the pen experiments was 7.1 ($\pm$ 5.1, n = 520) in Similk Bay and 6.4 ($\pm$ 7.2, n = 240) in Skagit Bay. The densities in Similk Bay averaged higher than those in Skagit Bay; and a students' "t"-test showed that the two means were significantly different at the 99 per cent confidence interval. Because the core samples were sieved through a 0.495-mm-mesh screen and the grab samples were sieved through a 1.0-mm-mesh screen, the densities could not be compared.

The mean monthly densities of individuals per core from the vicinity of the north-side pens are included in Fig. 8.3-11. Similar data from the south-side pen area were not plotted because of the lack of continuity across time. The mean density of individuals tended to increase over the sampling period, but no explanation of this trend is readily available. Seasonal peaks in densities occurred in spring of 1970 and 1971; and low levels of abundance occurred in late summer and fall. An examination of the counts for individual species failed to show any particular species that would account for these increases but indicated a general increase in the majority of the dominant species during these peaks. The spring and early summer are normally the periods of larval recruitment to the sediments; therefore it seems reasonable to expect increases during this time of year. Declines in late fall may be due to the toll of predation during summer on the infauna and lack of new recruitment.

Table 8.3-2. Summary of the mean number, standing crop in g/m^2, and species diversity, H, of benthic infauna in 5 1/10 m^2 grab samples from 20, 40, and 60 ft in Similk and Hope Island Bays. Sampling locations are shown in Fig. 8.2-3

Depth (ft)	Location	Date	H	Mean number per sample	Mean total weight of invertebrates (g/m^2)
20	Similk Bay	2/72	1.715	103 (SD = 48)	0.298 (+0.06)
40	Skagit Bay	12/70	3.595	59 (SD = 30)	0.314 (SD = 0.31)
40	Similk Bay	12/70	3.537	130 (SD = 62)	0.894 (SD = 0.27)
60	Skagit Bay	12/70	4.094	144 (SD = 53)	0.835 (SD = 0.08)
60	Similk Bay	12/70	4.013	409 (SD = 102)	1.065 (SD = 0.15)

[1] Sampling locations are shown in Fig. 8.2-3.

[2] Total weights do not include barnacles or echinoderms.

8.3.5.3.2 Microfauna. The results of the analysis of microfauna found in core samples from inside and outside the underwater pens are listed in Table 8.3-3. The nomenclature of many of the recognizable forms is pending expert assistance. The diatoms were sorted on the basis of the shape of the frustule. The most abundant diatom type was type A, tentatively identified as *Coscinodiscus* sp. Specific names will be attached to the type classifications in the near future.

The most abundant Foraminifera was *Vermeulina* sp. Several forms of rotoloid Foraminifera may be recombined under one species when identification in received. A combination of these rotoloid species would make them the numerically dominant species. At least three different species of aranaceous Foraminifera were commonly collected in the samples. Aranaceous species are characteristic of estuarine and brackish water conditions.

Identification of harpacticoid copepods, frequently encountered in the microfauna portion of the core samples, was made impossible by the sample drying process. Small unidentified pelecypods and ostracods were counted in the samples. As in the harpacticoid copepods, the majority of these specimens were badly distorted by the sample drying process.

A "student's t-test" comparison of the mean number of Foraminifera inside the pens to the mean number outside showed that there was no significant difference between the two means. A similar test of the mean number of diatoms per core sample inside and outside the pens indicated there was no significant difference at the 99 per cent confidence level. There was a significant decrease in the mean number of harpacticoid copepods, pelecypods, and ostracods in core samples taken from inside the pens. The radiolarians were significantly more abundant inside the pens.

Table 8.3-3. Summary of the mean number and standard deviations of microfauna species found in core samples from inside and outside the underwater pens during the period of October, 1970 to June, 1972

Diatoms	Outside (n=14) $\bar{x}$	Outside (n=14) Standard deviation	Inside (n-17) $\bar{x}$	Inside (n-17) Standard deviation
Type A	131.00	59.42	149.73	56.40
B	49.82	17.63	48.66	24.01
C	24.17	14.09	26.53	14.33
D	9.29	5.36	8.73	4.91
E	29.52	17.29	28.46	20.62
F	23.05	11.48	27.06	20.98
G	3.17	2.20	3.33	2.93
H	0.12	0.34	0	0
I	9.80	4.61	12.35	5.20
J	1.14	1.06	2.37	3.65
K	6.88	5.78	9.08	9.52
L	4.35	4.80		
Total	281.47	113.11	315.80	129.61
Foraminifera				
Globigerina sp.	22.42	48.29	39.42	51.24
Rotoloid A	5.71	7.82	4.84	4.53
Rotoloid B	41.70	61.99	15.86	30.24
Rotoloid C	21.11	15.14	22.66	18.36
Rotoloid D	12.23	10.26	14.06	25.81
Elphidium idet.	3.76	3.52	5.26	6.16
Rossalina sp.	29.64	29.51	27.26	29.29
Verneulina sp.	45.64	27.15	46.86	19.82
Buliminella sp.	4.47	6.08	2.07	3.27
Aranaceous A	7.94	6.35	8.13	7.34
Aranaceous B	5.41	3.47	6.40	5.45
Aranaceous C	6.23	4.87	4.93	3.42
Aranaceous D	0.17	0.37	0.14	0.36
Quinqueloculina sp.	0.13	0.33	0	0
Triloculina sp.	0.52	0.93	0.42	0.78
Uvigerina sp.	8.18	6.40	8.57	7.05
Spiroplectammina sp.	5.54	3.77	5.15	4.51
Misc. forans	18.41	13.91	16.73	12.23
Total	224.11	144.28	206.33	131.81
Harpacticoida	1.07	1.37	0.76	0.59
Pelecypoda	0.20	0.44	0	0
Gastropoda	0	0	0	0
Ostracoda	3.14	2.72	1.28	1.48
Radiolaria	1.00	1.30	1.60	1.72

8.3.5.4 Invertebrate Diversity

8.3.5.4.1 Trawl and Trynet Catches. The diversity indices, D, species richness; H, Shannon-Wiener index; Hw, Shannon-Wiener index of weights; number of species, and total number of individuals were calculated for the samples obtained by otter trawl and trynet and are summarized graphically in Figs. 8.3-8 and 8.3-9, respectively.

The five parameters shown in Fig. 8.3-9 for trynet samples were examined by analysis of variance by location and month. The only parameter that differed significantly between stations was H; the difference was significant at the 95 per cent confidence level. When the parameters for all three stations were compared by month, a significant difference was found in the monthly D values at the 95 per cent confidence level. The number of species also differed by month at the 99 per cent confidence level.

The parameters of the invertebrate catch by otter trawl, shown in Fig. 8.3-7, were analyzed in the same fashion as the data for the trynet samples. No significant differences was found in the 1971 catch at the 95 per cent confidence level between months or stations. For the 1972 catch, Hw was significantly different at the 95 per cent confidence interval between stations. The 1971 results should be considered as tentative because during this period information on the invertebrate catch was not rigorously collected and was considerably biased.

A qualitative examination of the invertebrate catch indices suggests some seasonal pattern. The otter trawl catch of *C. magister* seen in Fig. 8.3-10 shows an obvious summer increase. Hope Island Bay invertebrate catches show an increase in abundances and in H and Hw during the winter months. The reduction in the Skagit River discharge during this time of year might favor the influx of more oceanic species. Winter temperatures and photoperiod may also cause an offshore migration from the shallow margins of the bay into the deeper basins and thus produce a temporary increase in abundance and diversity in these deep regions. Diversities in Similk Bay show an increase during this same period followed by a sharp drop in April. This pattern would tend to fit the first hypothesis more closely; the invertebrates might be attracted into the more oceanic winter

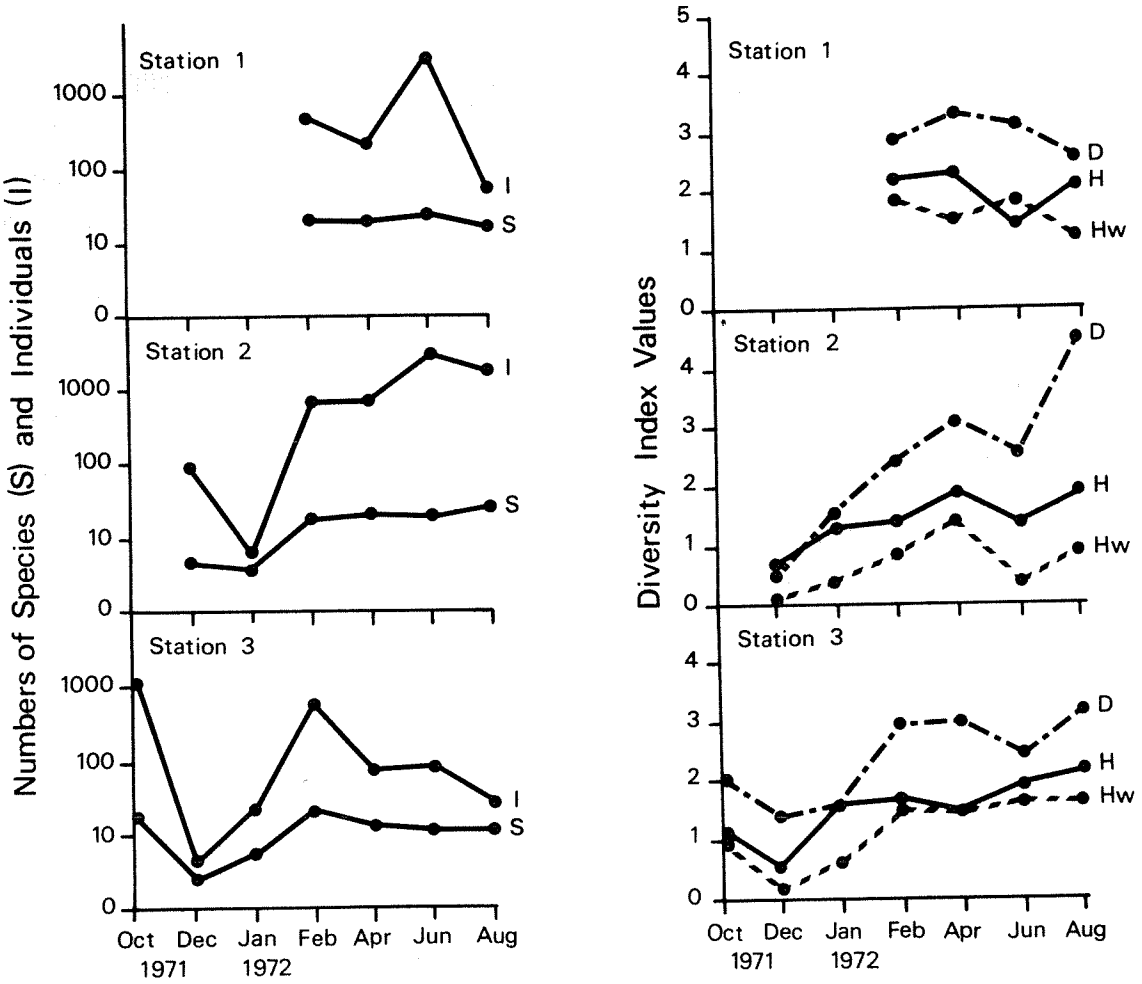

Fig. 8.3-8. The number of individuals and species of invertebrates collected by otter trawl. Included are the corresponding diversity indices, H, Shannon-Wiener; D, species richness; and H_w, Shannon-Wiener diversity of weight calculated for invertebrate catches.

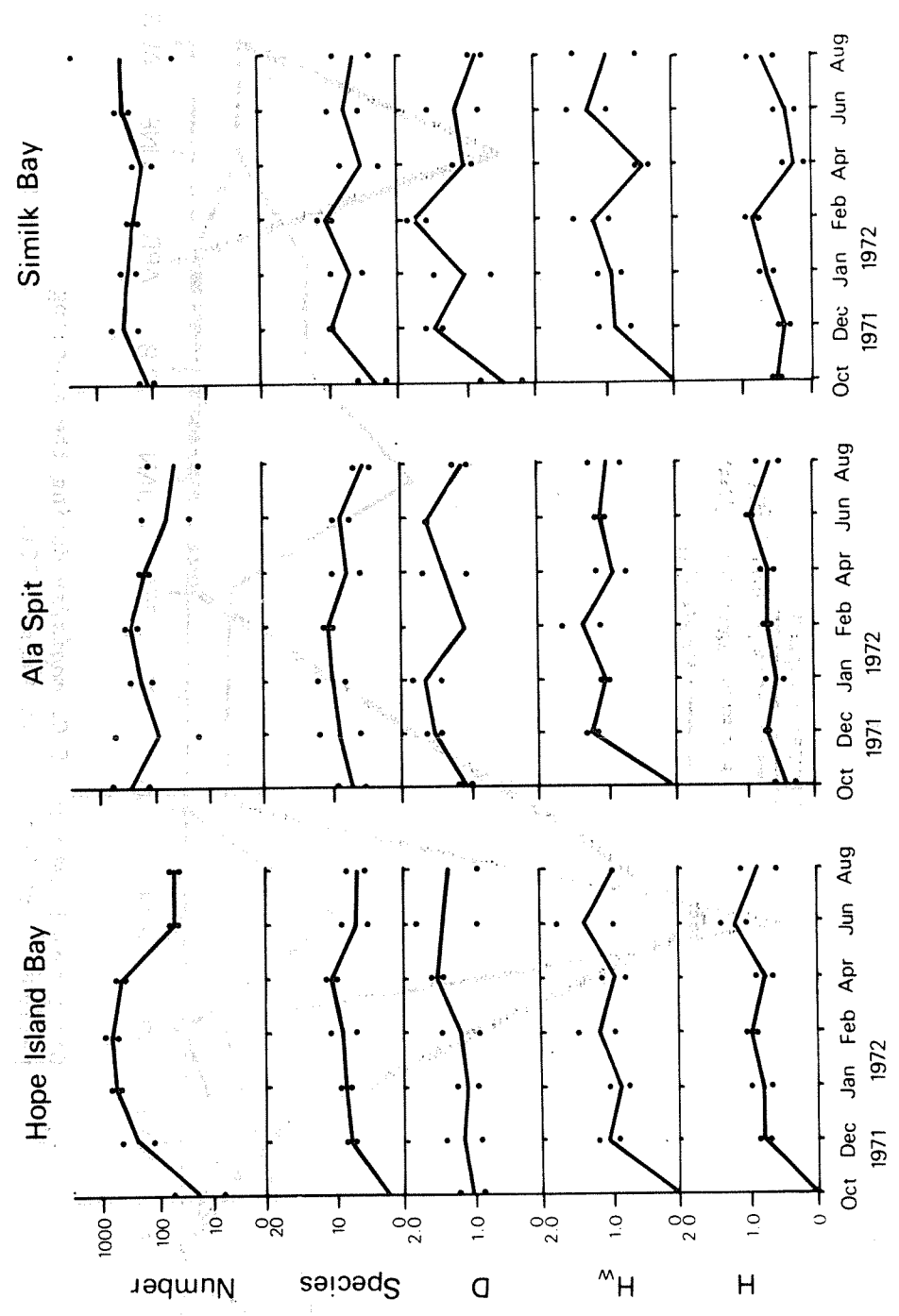

Fig. 8.3-9. The number of individuals and species if invertebrates collected in trynet samples. Also included are the corresponding diversity indices, H, Shannon-Wiener; D, species richness; and H_w, Shannon-Wiener diversity of weight calculated for the trynet invertebrate catches.

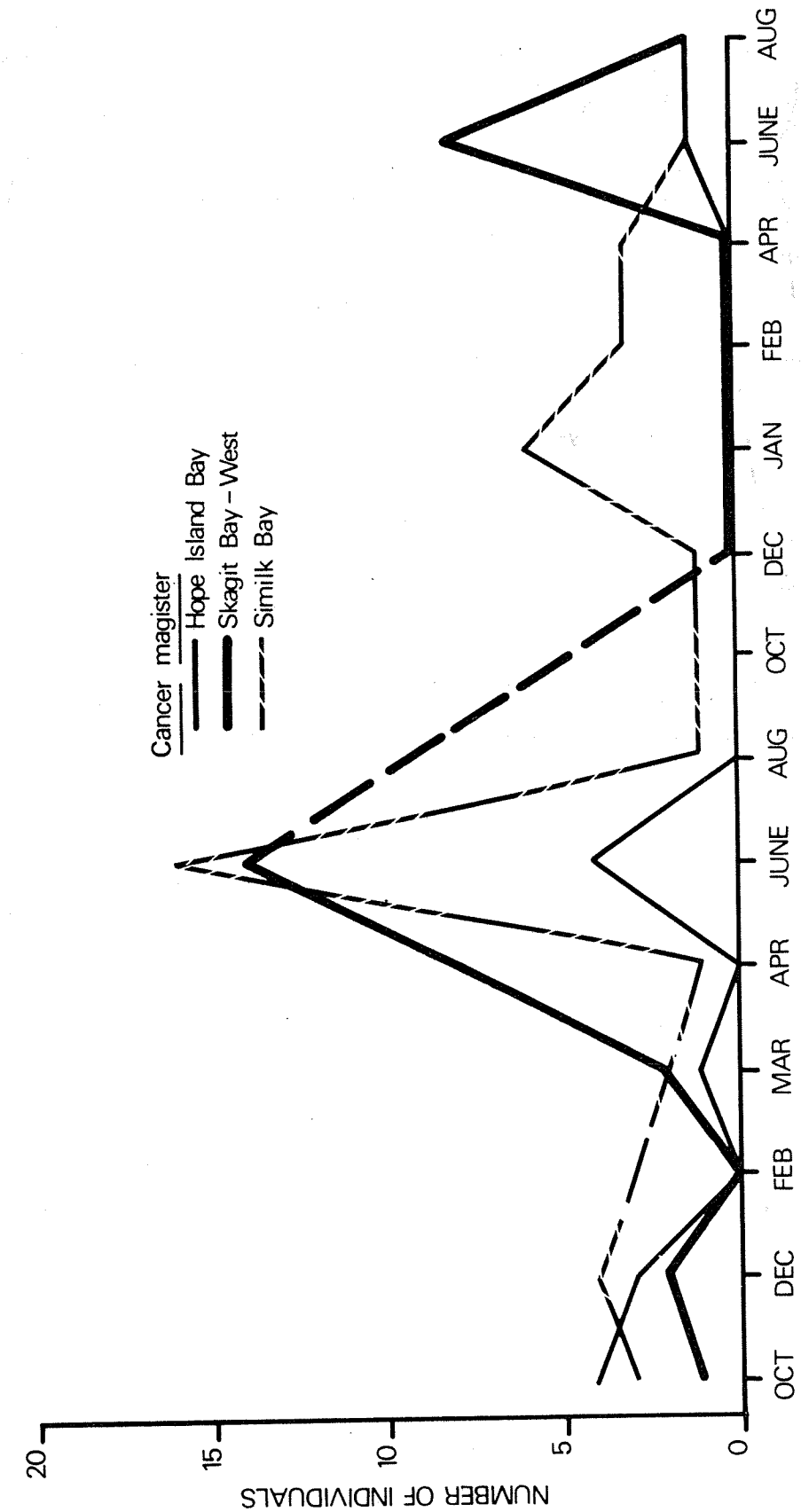

Fig. 8.3-10. Otter trawl catches of *C. magister* during the sampling period of October 1970 to August 1971.

conditions of the Bay and then retreat before the April freshets. Before any conclusion can be drawn, several years of seasonal observations would be required.

8.3.5.4.2 Grab Samples. The mean diversities, H, for the series of grab samples described earlier are listed in Table 8.3-2. H was found to differ significantly at the 95 per cent confidence level between stations in a one-way analysis of variance. A linear regression analysis of diversity versus depth showed the two variables to be significantly correlated ($r=0.901$). The line relating the two variables explained a significant amount of variance at the 99 per cent confidence level. The finding that diversity increases with depth is in keeping with the results of many benthic studies (Lie, 1969; Sanders, 1969; Johnson, 1970).

8.3.5.4.3 Core Samples. The calculated diversities for the core samples taken from January 1970 to July 1972 are presented graphically in Fig. 8.3-11. The Shannon-Wiener and Fager "Number of Moves" indices were scaled as suggested by Fager (1972) so that the two indices could be compared. D, species richness, is also included on an upper scale. A one-way analysis of variance showed no significant differences at the 99 per cent confidence level between years. A students' "t"-test of the difference between the mean diversity indices, H, for Skagit (1.891 ± 0.201) and Similk Bay (2.112 ± 0.351) core samples showed them to be significantly different at the 95 per cent confidence level.

Seasonal trends in the diversities were less obvious than geographical differences. A gradual increase in D, species richness, was apparent but may have been due to a progressively improving recognition of species in the sorting process. Abrupt changes in both H and NM occurred in April 1971 and in May 1972. Increases in numbers of individuals per core as a result of spring larval recruitment caused a depression of the H and NM curves in 1971 and 1972. The increasing abundance of a few of the dominant species caused a decrease in the diversity of species. In general the diversity indices remained unchanged throughout the two-and-one-half-year sampling period.

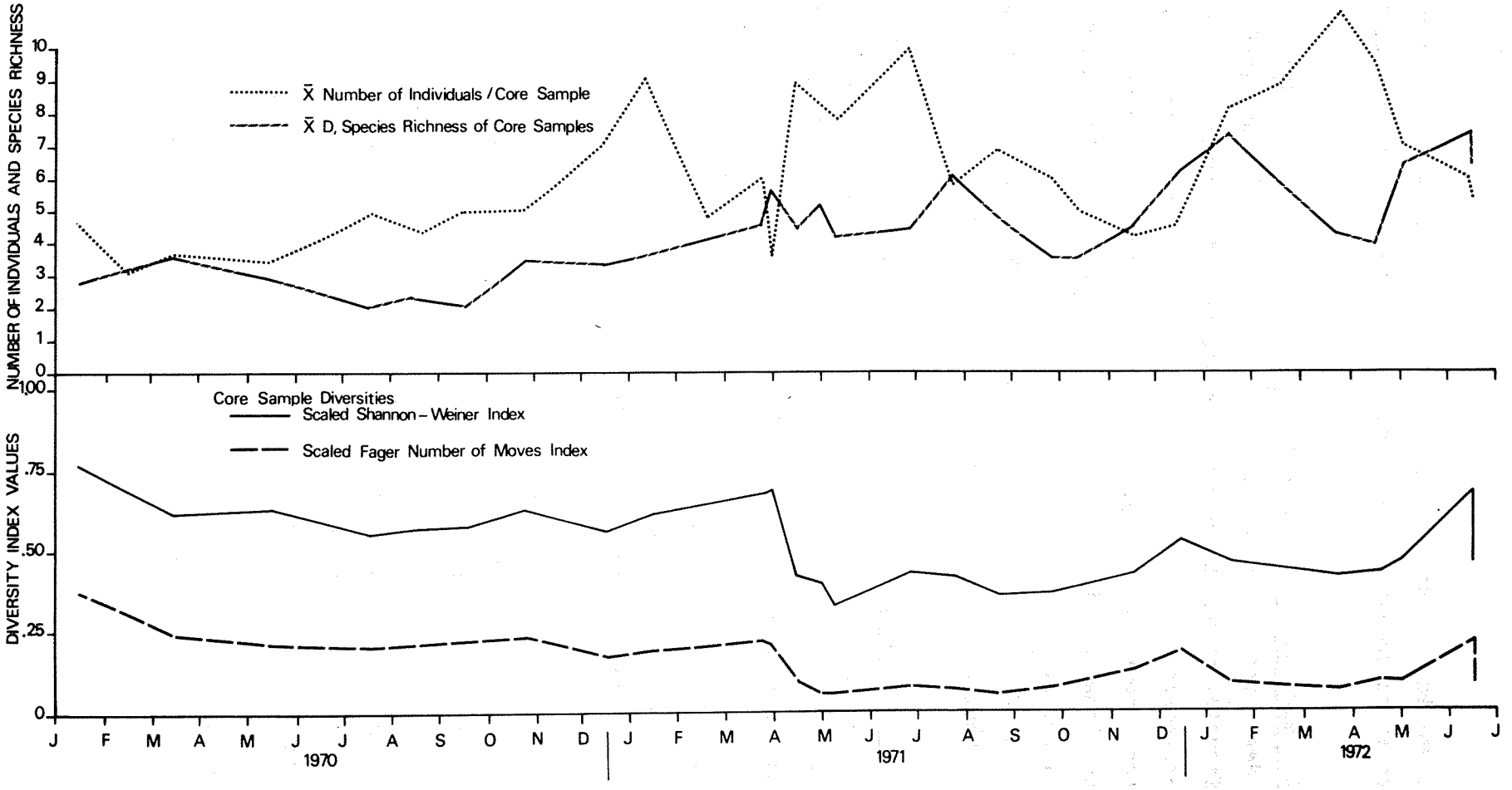

Fig. 8.3-11. The mean diversities, scaled Shannon-Wiener, scaled Fager number of moves, and species richness of invertebrates collected in core samples taken outside the Similk Bay underwater pens. Also included are the mean number of invertebrates per core sample.

8.3.5.4.4 Environmental Manipulation. The calculated mean diversities and densities for the 892 core samples collected in the crab predation study are presented in Tables 8.3-4 and 8.3-5, respectively, by experiments and treatments. The data were analyzed separately by experimental area. A one-way analysis of variance of the treatment means of H showed them to differ significantly at the 99 per cent confidence level. As can be seen in Figs. 8.3-12 and 8.3-13 the diversities of the treatment cores were directly proportional to the level of crab predation. The figures were plotted as an example of the results in the two other experiments not graphed. A line fitted by least squares to the relationship between diversity of the treatment cores and density of crabs in the treatments explained a significant amount of the variance at the 95 per cent confidence level.

In practically all cases, by the end of the first month the diversities within the pens had fallen significantly below the diversities of the outside control samples and the differences in treatment diversities had become established. The levels of diversity among treatments remained nearly proportional throughout the experiments, but tended to fluctuate in accordance with changes in outside diversity.

The mean densities for the treatments were found to differ significantly at the 95 per cent confidence level in a one-way analysis of variance: the mean densities were highest in the pen without any predation and declined with increasing levels of predation. A linear regression analysis demonstrated a significant relationship at the 95 per cent confidence interval between mean density of treatment group infauna and number of crabs in the corresponding treatment group.

A qualitative examination of the treatment cores showed that the invertebrates removed in predation were surface-dwelling forms. These included both the ostracods, *Euphilomedes producta* and *Euphilomedes carcharodonta*. The number of individuals of *Transenella tantilla* also markedly declined with increased crab predation. The assemblage of polychaetes appeared to be little changed with the exception of *Praxiella gracilis*, which was present in noticeably lower concentrations.

Table 8.3-4. The mean diversity indices H, Shannon-Wiener, and D, species richness, of core samples from each treatment group in the underwater pen experiments

	Number of crabs in treatment group											
	3		2		1		0		1		0	
	Diversity indices											
	H	D	H	D	H	D	H	D	H	D	H	D
	Experiment started 12/12/69											
1/15/70	2.016	3.020	1.725	2.627	0.950	0.868	0.661	0.713				
2/15/70	2.112	3.410	1.811	2.691	1.112	0.912	0.512	0.622				
3/15/70	1.916	2.555	1.652	2.002	1.433	2.019	0.936	0.910				
6/15/70	1.715	2.524	1.399	2.002	1.255	1.442	0.822	0.913				
7/18/70	2.270	2.815	1.870	2.455	1.806	2.215	1.630	2.154	1.835	2.235	1.679	2.503
8/10/70	2.097	2.706	2.075	2.386	1.975	1.883	1.753	1.791	1.570	1.381	1.362	2.015
	Pens moved - Experiment started 12/6/70											
1/10/71	1.993	2.631	1.826	2.333	1.613	2.044	0.781	0.812	1.213	2.011	1.185	2.331
2/18/71	2.001	2.715	1.851	2.582	1.751	2.403	0.750	0.876	1.355	2.319	1.563	1.343
4/12/71	1.520	1.763	1.281	3.032	1.258	2.053	0.812	1.111	1.003	0.287	0.815	1.543
5/10/71	1.501	2.450	1.329	2.609	1.235	3.215	1.149	1.333	1.131	2.455	0.975	1.718
6/25/71	1.625	3.651	1.348	1.962	1.303	2.000	1.182	1.218	1.474	2.171	1.115	1.888
8/15/71	1.798	6.315	1.710	3.236	1.157	3.236	0.991	0.913	1.575	1.401	1.233	2.898
	Pens moved - Experiment started 12/2/71											
1/15/72	2.232	5.390	2.122	5.081	1.947	3.654	1.311	2.924	1.951	3.118	1.468	2.477
2/19/72	2.051	3.110	1.919	4.762	1.847	3.303	1.412	2.663	1.822	2.999	1.112	1.834
3/21/72	2.116	4.057	1.779	2.968	1.442	2.012	1.303	1.978	1.658	2.801	1.001	1.769
6/16/72	2.158	5.101	2.177	3.729	2.154	3.620	1.886	3.050	2.167	2.209	1.563	1.100

Table 8.3-5. The mean number and standard deviations of invertebrates in core samples from each treatment group in the underwater pen experiments

	Treatment group															
	1		2		3		4		5		6		7		8	
	Number of crabs in treatment group															
	3		2		1		0		Control		Control		1		0	
Date	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
1/15/70	7.1	7.1	4.1		2.2	2.6	6.3	7.7	4.7	4.8	3.0	2.9				
2/15/70	1.2	1.4	1.8	1.3	3.5	3.7	6.2	5.6	3.1	3.4	2.5	2.0				
3/15/70	1.6	1.7	2.0	0.8	2.4	2.1	5.4	4.4	3.6	3.1	5.2	4.3				
6/15/70	0.9	1.1	3.3	2.6	4.0	2.5	5.7	4.7	4.2	3.7	6.9	10.1				
7/18/70	2.2	2.0	3.1	2.2	3.7	3.7	9.3	8.8	4.9	5.8	4.2	7.3	5.4	5.5	8.7	7.0
8/10/70	1.9	2.3	2.7	1.9	3.7	2.3	8.6	8.4	4.4	4.7	4.1	7.4	3.1	4.1	7.9	6.1
TURNED PENS STARTED 12/6/70																
1/10/71	5.5	3.4	12.1	9.2	4.6	4.5	9.0	8.1	9.1	8.8	8.7	8.6	6.0	6.0	10.0	8.5
2/18/71	1.1	0.9	4.1	7.3	7.3	6.5	8.2	9.2	4.7	3.7	3.6	3.3	5.1	4.8	9.3	10.9
4/12/71	2.4	2.2	5.6	8.8	3.9	2.9	10.1	8.3	8.5	9.2	7.2	6.2	5.8	5.2	11.6	13.2
5/10/71	2.5	3.1	1.9	2.7	5.2	4.5	11.0	12.3	7.8	7.8	9.1	11.5	3.2	3.7	7.8	8.2
6/25/71	1.9	1.2	2.4	2.4	5.0	3.2	15.1	11.9	10.0	12.5	8.3	9.9	4.8	5.2	9.4	9.9
8/15/71	2.6	1.8	3.0	3.9	4.8	6.4	14.3	11.7	6.8	5.9	4.5	7.4	3.7	4.0	12.8	10.3
TURNED PENS STARTED 12/1/71																
1/15/72	6.6	5.0	10.2	11.9	3.7	2.6	7.8	8.9	8.3	6.5	3.6	2.8	5.1	2.9	8.2	6.9
2/19/72	3.0	3.3	9.9	9.0	4.6	4.0	5.5	5.6	8.9	7.0	2.1	1.7	4.1	3.4	4.6	5.8
3/21/72	3.4	2.8	4.3	3.3	5.0	4.5	12.2	12.4	11.4	8.5	5.9	8.2	4.6	4.0	15.2	11.1
6/16/72	1.2	1.2	1.1	0.9	2.2	2.4	11.6	10.3	6.0	6.6	8.3	9.5	2.7	3.3	11.2	9.1

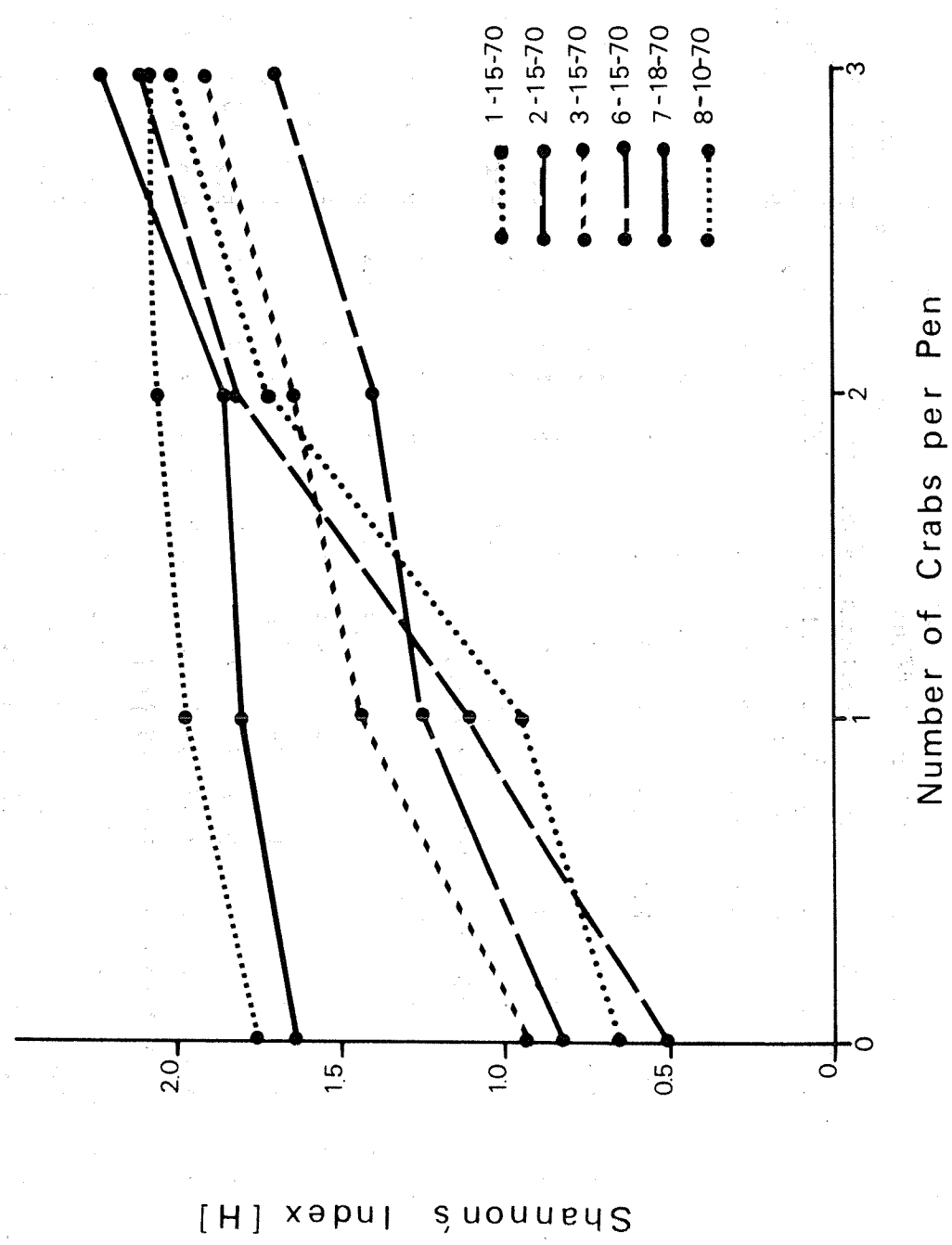

Fig. 8.3-12. The mean species diversity, H, of core samples collected in the underwater pen experiments on the indicated sampling dates from January 1970 to August 1970.

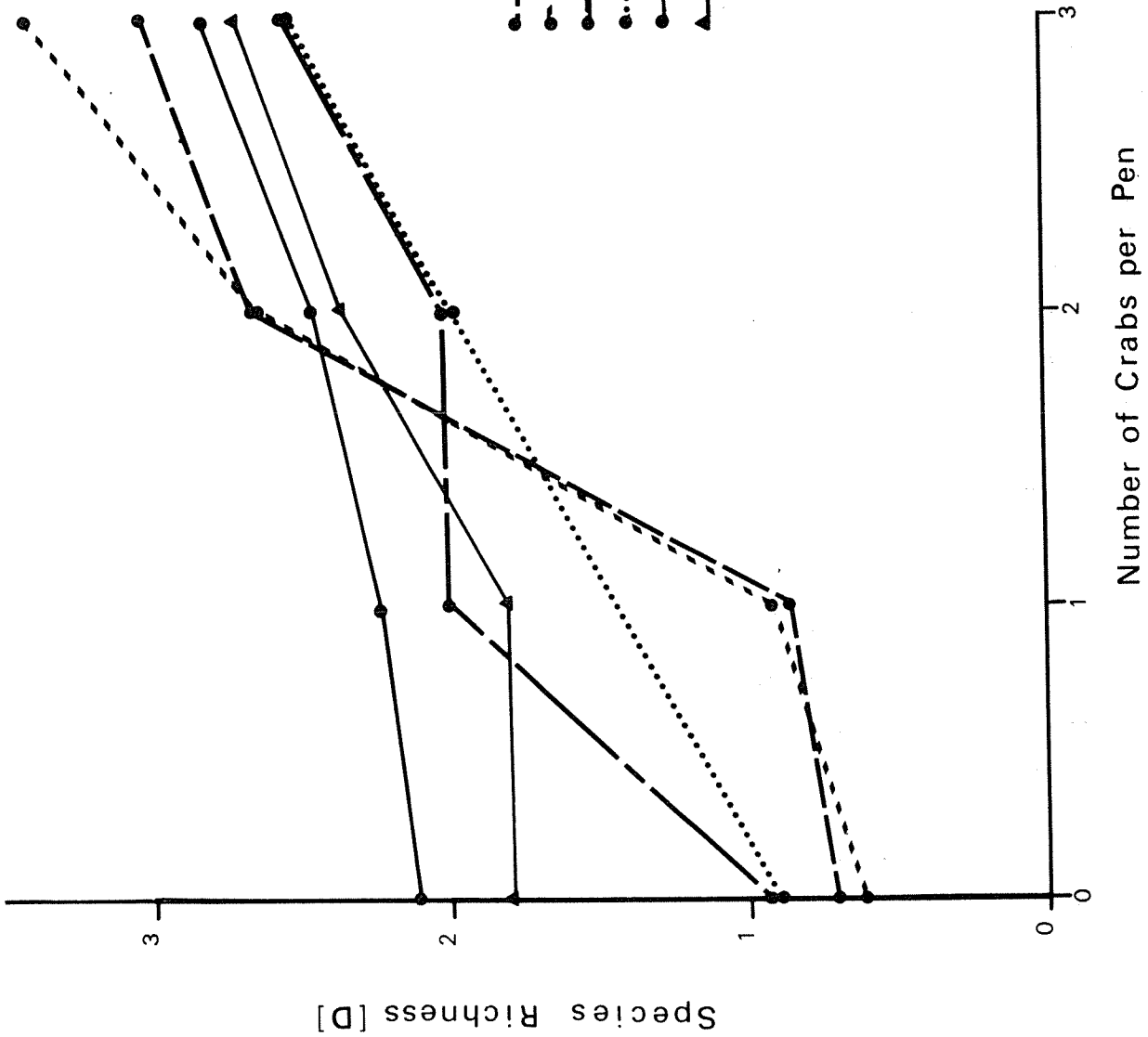

Fig. 8.3-13. The mean species richness, D, of core samples collected in the underwater pens on the indicated sampling dates from January 1970 to August 1970.

Throughout the experiments an attempt was made to clear the pens of fouling organisms. Several times the pens were covered between sampling periods because of the rapid settlement and growth of laminarian algae. During one sampling of the Hope Island Bay pens the algae were cleaned from one of the pens but not the other, and the following month the pen that had been cleaned was found to be covered with newly settle *Balanus cariosus*; whereas the pen that had not been cleaned of its algal cover was found to be free of barnacle growth. The algae were later cleaned from this second pen, but the pen remained uncolonized by barnacles; evidently the algae had prevented settlement and were removed past the peak settling period of the barnacles. From mild to heavy algal growth was present on the cages throughout the spring and summer months, usually accompanied by stands of various hydrozoans. During the winter months the laminarians would die back, leaving low stands of small red algae.

Of the nine crabs used in the three crab treatment group, seven died during the course of the experiments and were replaced within the month. Two out of the six crabs in the two crab treatment groups died during the experiments and were also replaced. The majority of the crab mortalities occurred during the fourth and fifth months of the experiments. The most likely cause is starvation from insufficient food in the pens.

8.3.5.5 Factor Analysis of Core Samples

The results from core samples collected in the predation experiments and control areas were treated by factor analysis. The samples were grouped by sampling data for analysis. Each analysis was devoted to the results of cores from compartments of 0, 1, 2, and 3 crabs as well as the results from cores taken on both sides of Kiket outside of the experimental pens. A complete set of samples, 10 from each of the six compartments and 20 from each of the two control areas, represented 100 samples, the maximum number that the program, FORMAN, can handle.

A trial calculation of the R-mode, species commonality, for two sets of samples, January 10, 1971 and June 10, 1971, failed to separate more than one species assemblage. Of the variance 73 per cent was found in factor one, 6 per cent in factor two, and the remainder was unaccounted for. Based on

the lack of noticeable changes in the rank and occurrence of species in the sample data, the absence of more than one factorable assemblage of species was expected. Consequently, analysis in the R-mode was not continued for the remaining samples.

Factor analysis of the monthly sample sets in the Q-mode produced distinct results. In nearly every case three major variance groups were seen, with a reasonably consistant pattern. Figure 8.3-14 is an example of these patterns as determined by isopleth analysis of the scattergram of data points plotted in the factor one-factor two coordinate system in the computer printout. Factor one accounted for an average of 37 per cent of the total sample variance and represented the outside control samples. Factor two contained an average of 16 per cent of the sample variance and represented the treatment groups with 1, 2, and 3 crabs. Factor three accounted for an average of 6 per cent of the variance in the data and was associated with the treatment groups without crab predation.

As seen in Fig. 8.3-14 the treatment groups form discrete clusters, although samples occur outside them. These outside sample points represent areas of transition in the data fields. The change in species abundance and composition within each treatment group had to occur gradually as the effect of predation continued. There were undoubtedly areas in the compartments that were affected sooner than others. The patchy effect of predation in the compartment would leave some areas relatively unchanged or partially changed. Core samples from these areas might be similar to areas in other treatment groups and therefore would be plotted away from the center of its treatment group sample points and possibly associated with another treatment group.

The effects of manipulated levels of predation were measureable through the use of factor analysis. The crab predation produced core samples with a high degree of commonality which caused them to be plotted as an assemblage at the upper end of the ordinate. The distribution of individuals among the species, as also seen in diversity calculations, produced a commonality in these predated groups.

The separation between the results of core samples taken from inside the predated pens and outside the pens is more distinct in the results of

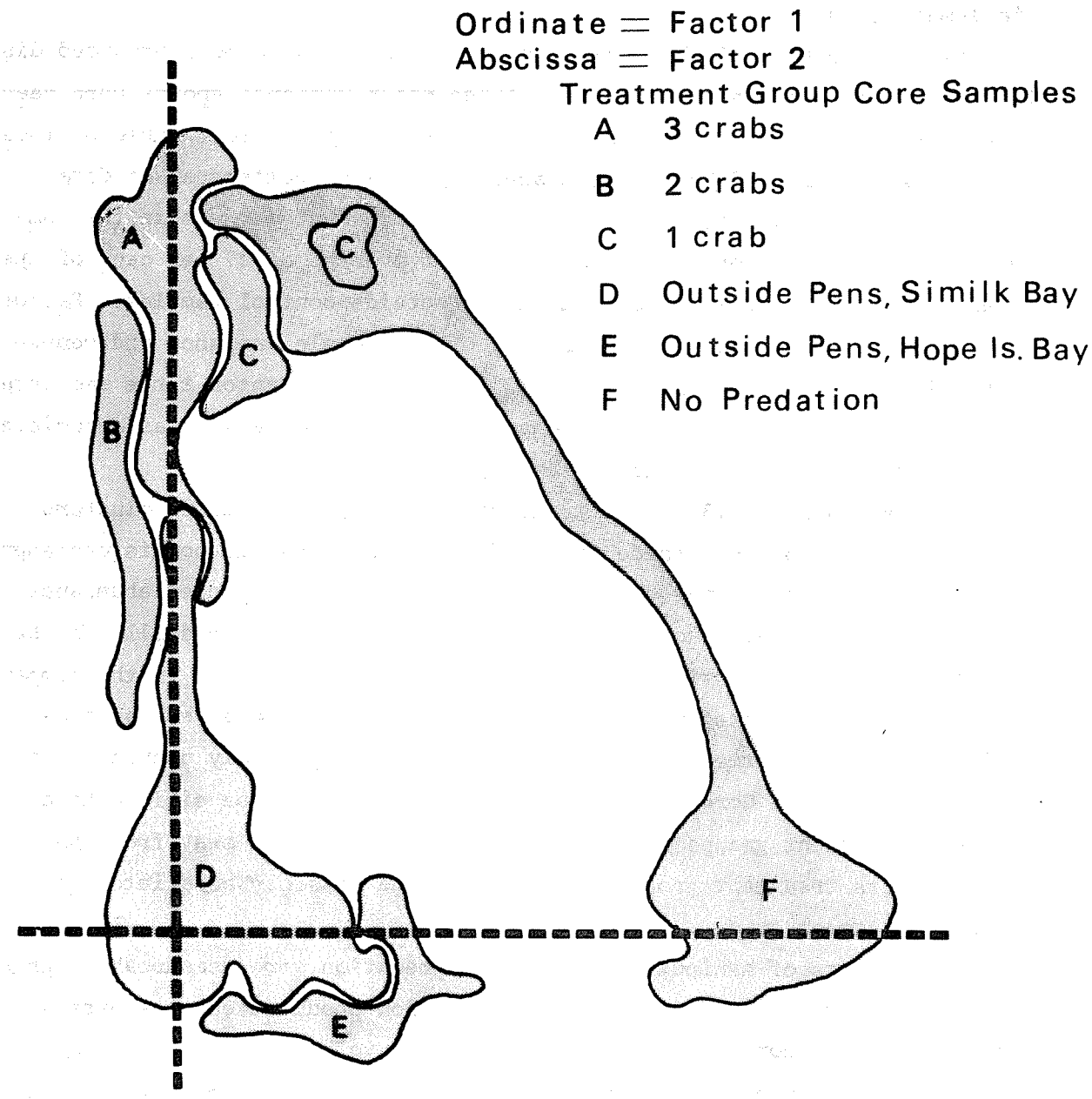

Fig. 8.3-14. A representative example of the results of factor analysis analyzed by treatment group isopleths. Isopleths are drawn around the core sample vector points plotted in the factor one and factor two coordinate system.

factor analysis than in diversity calculations. This increased separation is due to the retention of species information from each core sample in factor analysis. There were small changes in the species composition of infrequent amphipods but not in the relative numbers of these infrequent species. The use of diversity formulae had sacrificed information on changes in species composition in contrast to the factor analysis which incorporated this information; thus when these species changed an additional separation was noticeable in the results of factor analysis.

While the results from the predation experiments did not produce large changes in species composition, factor analysis was sensitive to the species change. Both factor analysis and diversity calculations demonstrated differences in the treatment groups, but factor analysis increased the separation of treatment effect by responding to changes in species composition. The separation between predated pens and the pens in which predation was excluded is more distinct in Fig. 8.3-14 than in Fig. 8.3-12. This result also demonstrates, as discussed above, the increased sensitivity of factor analysis over diversity calculationsto faunal changes.

8.3.5.6 Analysis of Stomach Contents

The results of analysis of the stomach contents of the Dungeness crabs and flatfish samples are listed in Table 8.3-6. In both cases a portion of the contents was an unidentifiable mass of organic material. In many instances polychaet setae were present, as well as body parts. These were frequently recognizable as such but were either extremely difficult or impossible to identify to species. These items were recorded under an undifferentiated "polychaet" category. Fish parts, such as scales and vertebrae, were found in a few stomachs. These were recorded under "fish," undifferentiated, as in the case of the polychaete parts.

Crustaceans were the predominant food items in all the stomachs examined. Gammerid amphipods were the primary prey items in individuals of the species *Parophrys vetulus*, *Lepidopsetta bilineata*, *Lumpenus sagitta*, and *Cancer magister*. Mysids were the most abundant prey item in species of *Psettichthys melanostictus* and *Leptocottus armatus*. The commonly occurring gammerids in all stomach samples were *Photis lacia*, *Heterophoxus*

Table 8.3-6. Mean number and rank of major prey items in stomach samples of five species of demersal fish and *Cancer magister* caught in a trynet and crab pots during June, 1971. Samples were taken in Similk and Hope Island Bays. (+) indicates less than 0.5 individuals per stomach

Species	Number examined	Mean length of specimens (cm)	Gammerid amphipods										Ostacods				Cumacean		Tanaids				Pelecypods								Polychaets				Fish parts
			Photis lacia		*Protomedia* sp.		*Paraphoxus oculatus*		*Orchomene anaquela*		*Heterophoxus oculatus*		Total		*Euphilomedes carcharodonta*		*Euphilomedes producta*		*Eudorella pacifica*		Cumacea unidentified		*Leptochelia dubia*		*Leptognathia longiremis*		Mysidea unidentified		*Crago franciscorum*		*Transenella tantilla*		*Cardium corbis*		Pelecypoda unidentified		Polychaeta unidentified		Nematoda		
			X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	X	r	
Parophrys vetulus	20	8.6 (±1.6)	21	2	9	3	+		+		6	4	32	1	2	5		+	+		+			6	4										+			+
Lepidosetta bilineata	20	13.1 (±10.4)	13	2		+		+			3	6	18	1		+						2	7		+		6	5				8	4				9	3		
Platichthys stellatus	18	21.2 (±5.1)	3	4		+						+		5	3	1	6		+											2	5	9	2				12	1		
Psettichthys melanostictus	20	9.1 (±0.5)	2	5	5	3			+			+		11	2						+				3	4	18	1								2		5		
Leptocottus armatus	20	12.9 (±1.6)	8	3	2	6			+		2	6	16	2											4	4	21	1	8	3						+		3	5	+	
Lumpenus sagitta	25	20.0 (±7.3)	24	4	26	3	+		+		6	6	62	1					+				+		38	2					4	7		+			8	5	+		
Cancer magister	50	16.2 (±2.1)	6	3	5	4			+		2	6	11	1	5	4	3	5	+		+		+		8	2					6	3			+					+	

oculatus, and *Protomedia* sp. The ostracods, *Euphilomedes carcharodonta* and *E. producta*, were common prey items of fish of the species *Platichthys stellatus* and Dungeness crabs. Finally, the tanaid, *Leptognathia longiremis*, ranked as the second most common item in the stomachs of Dungeness crabs and fish of the species *L. sagitta*.

8.3.6 Discussion

8.3.6.1 Species Collection

A qualitative comparison of the species collected in the present study with those found by Lie (1969) indicated some distinct differences. Lie's (1969) study represents the only Puget Sound study available for a comparison. *Transenella tantilla*, one of the dominant shallow-water species of the Kiket Island infauna, was not present in Lie's studies. Since the normal distribution of *T. tantilla* is restricted to shallow bays, it would not be expected to occur in Lie's deeper samples. Several species of amphipods were also unreported in Lie's studies. At least three of these, *Pleusymptes* sp., *Apherusa* sp., and a stenothoid, probably represent new and undescribed species (Barnard, 1973, personal communication). The occurrence of *Dulichia* sp., unreported by Lie (1969), represents a new record of the genus for the area and a probable new species (Barnard, 1973, personal communication). Finally, the occurrence of *Monoculodes crassirostris* is the first record of this northern species this far south (Barnard, 1973, personal communication).

The ostracods *Leguminocythereis* cf. *L. filoplumosa* and *Acanthocythereis dunelmensis* were both unreported by Lie (1969). *A. dunelmensis*, originally described from Northumberland in Northern England, is quite varied and extends throughout the high latitudes of the Pacific, Atlantic, and Arctic (Benson, 1972, personal communication). *L. filoplumosa* was relatively common in the Kiket Island samples. Its distribution and range are incompletely known, therefore no conclusions on its absence in Lie's samples are possible. Finally, the third ostrocod found in the Kiket Island samples, but not Lie's was a new species, tentatively named *Tetragonodon (mayeri)* (Kornicker, personal communication). Since there are no other records of its occurrence, its absence from Lie's samples is unexplainable.

No differences were noted between Lie's polychaete collection and the Kiket Island species. This similarity may be due to the incomplete knowledge of the taxonomy of many which were unidentifiable beyond the generic level. The common polychaete species agreed very closely with those found by Lie (1969) and Woodin (1972) in the San Juan low intertidal.

8.3.6.2 Diversity of the Benthic Invertebrates

Measurements of the diversity of biological communities have become increasingly popular among ecologists. Their appeal is primarily expedience. The calculation of diversity enables the reduction of large volumes of data on abundance of species, which formerly occupied lengthy appendices, into an easily reported statistic. The shortcoming of the statistic is a loss of information on species, in other words, a change in diversity may be observed without an understanding of the specific cause for the change.

The usefulness of the method for reduction of data on a large number of species into a single statistic may outweigh the loss of information. This argument has particular relevance in present-day studies of environmental quality directed toward problems of pollution. Although the diversity index contains no information about the differences in species between different collections, it does provide measurements of the quality of different samples of species from the same species assemblage. In background studies prior to environmental alterations, measurements of diversity have proved useful in detection of changes in samples from the same area. Mihursky (1966), in his recent study of the effect of thermal discharge into the Patuxent River, was able to demonstrate biological alterations based on changes in measurements of diversity. The interpretation of the changes in diversity remains as the task of the biologist, who must examine the collections for changes in species composition and interpret their biological significance. The measurements of diversity reported under the preceding results serve two functions. The first use is, as mentioned above, to furnish background information for possible postoperational comparisons should a power plant be built in the area. The second is to furnish information on normal diversities and seasonal changes for comparison with the diversities measured in the crab predation experiments.

Because only small spatial or temporal differences were seen in the diversity measurements, very little interpretation is necessary at this point. The lack of changes in diversity in invertebrate trawl samples is in sharp contrast to the changes in fish diversity in the same catches. The main cause of this difference in stability of diversity in the fish and invertebrate populations is the migratory ability of the fish. Many of the small invertebrates are not capable of making extensive seasonal migrations because of their size. In contrast, the majority of species of fish sampled can and do make large seasonal migrations. An English sole, *Parophrys vetulus*, tagged in the Kiket Island area was recovered at Neah Bay. Many other flatfish tagged and released near Skagit Island were recovered in the vicinity of Everett. The small shrimp, echinoderms, and crabs, which constitute the majority of trawl-caught invertebrate forms, would be capable of only very local movements.

Reduced diversities for the core samples were primarily associated with increased density of the dominant infauna species. Spring and early summer recruitment to the infauna populations produced small declines in the diversity indices H and D. The comparatively greater values in H and D during the later months of the year might be the result of reduced recruitment of the dominant forms and accumulated natural summer mortality on these populations. A decline in the abundance of the dominant species would place more importance on a greater variety of species in the sample collection, thus increasing the diversity of the collection.

The scaled H diversities for the core samples taken from outside the underwater pens were lower than those calculated by Fager (1972) from Sander's (1960) study of Buzzard's Bay. The infauna diversities in the present study would place the community near the center of the continuum between the biologically accomodated community and abiotic described by Sanders (1969). In his continuum the diversity of the Kiket Island community would be more similar to a physically controlled community than the biologically accommodated. The fact that the diversities of the core and grab samples were lower than those reported by Lie (1969) for Puget Sound may reflect the influence of the discharge from the Skagit River. The areas sampled by Lie could be characterized as having more physically stable conditions. The lower diversities of both grab and

core samples from the south side of Kiket Island would support the hypothesis that the less stable the water quality conditions are the lower the species diversities.

8.3.6.3 Diversity of Infauna and Predation by the Dungeness Crab

The results of the crab grazing studies clearly demonstrate that biological interaction is a determining factor in the diversity of the benthic infauna. The corollary that physical parameters do not affect diversity is not valid, however. The measured diversity of a community is a combination of both physical and biological parameters acting upon the species available to the area.

In the present study, the feeding activity of *C. magister* tended to eliminate the more commonly abundant species from the infauna. As Porter (1972) points out, the diversity of a collection may decline if the predator feeds in a "fine-grained" manner (MacArthur and Levins, 1964). In this instance the predator feeds on all prey in the proportion in which they occur and thus eliminate the rarer species. Porter continues with the converse. If the predator feeds in a "course-grained" manner, i.e., actively selects prey items, the diversity may increase if it selects the most abundant and fastest growing prey. Porter was able to prove his argument successfully in a study of the relationship between *Acanthaster*, the coral-feeding starfish, and coral species diversity. Evidently the crabs were feeding in a course-grained manner and thus increased the diversity of infauna within the predated treatment areas.

An examination of the results of analysis of the stomach contents supports the above feeding strategy for *C. magister*. The more abundant prey items in the stomachs sampled were the more abundant prey items in the core samples. The feeding behavior, as observed several times during SCUBA dives, would bear out this conclusion. When partially burrowed into the sediments, the crabs slowly sift through the sediments in front of them by alternately shovelling with the left and right chelae. According to McKay (1942), the bristles in the chelae are sensitive to the movement of small prey and aid the crabs in capturing prey. The predominance of *Transenella* and the ostracods *E. carcharodonta* and *E. producta* as prey items may

be the result of this feeding behavior. Amphipods would be capable of escaping the crab's claws more readily than either ostracods or clams. Because of the crab's limited ability to capture prey, it is effectively selecting prey items.

The removal of the ostracod and *Transenella* would have made available additional food and space to colonizing species. Because the pens were open to immigration by all the infauna species, it is likely that the available resources were quickly exploited. As Paine (1966) hypothesized, "local species diversity is directly related to the efficiency with which predators prevent the monopolization of the major environmental requisites by one species." His hypothesis was well supported by his finding that the removal of predation by the sea urchin caused a decrease in algal diversities (Paine and Vadas, 1969).

The results of removing all large predators, adult crabs and fish, produced the same effect as in Paine's sea urchin removal studies. The diversities were markedly lower because of the increase in the numbers of the few main species of prey. These were also very similar to the species of prey commonly found in the stomach contents of fish. The removal of fish predation must have contributed to the decrease in diversity seen in the pen without predation.

The finding that the outside diversities, H and D, remained higher than any of those for the predated treatments may be the result of several possibilities. One explanation is that the outside infauna was exposed to a higher level of predation than the infauna in the treatment where the density of crabs was highest. This may be possible since the pens excluded many of the larger fish. Another explanation is that the predation levels in the pens were extremely high. As Porter (1972) found, "species diversity is not increased on some of the Guam reefs where the Acanthaster plague destroyed almost 100% of the living coral." He suggested that such an abnormally high predation rate might be analogous to a severe physical damage due to storms. The density of crabs in all treatment groups was considerably higher than the densities of crabs calculated from sledding surveys and population estimates in Similk Bay (section 8.2.3.2.6). If on occasion crabs school, as some authors have suggested (McKay, 1942), the densities in the areas of the schools may be considerably higher than

calculated for Similk Bay if one assumes a uniform distribution. No such schools were observed in the sledding surveys, but they may have been missed by chance. If extreme predation is accepted as the cause of lower diversities in the pens than outside, as the predation rate in the pens decreased the diversity should have increased. In fact, the opposite results were obtained.

A third explanation might be a general degradation of the habitat within the pen by the presence of the pen. There was no way of assessing the effect of the pen, but it remains a strong possibility. The growth of algae and hydrozoa on the pen could easily have had an effect on the in-pen diversities. Shading of the sediments may have restricted light to the benthic diatoms and reduced benthic primary production. The preliminary results of the analysis of diatom abundances in core samples collected from inside the pens would contradict this argument.

The presence of hydroids and attached carnivores may have acted as a biological filter and reduced larval recruitment inside the pens. Woodin (1972) found that the diatomaceous layer that formed on the cage screen attracted polychaetes of the tube-building species and effectively eliminated their recruitment to the inside area of the pens.

The mean number of individuals in the core samples was inversely proportional to the level of predation. The highest standing crop occurred in the pen receiving no predation and probably had the lowest level of production as in the studies of Hayne and Ball (1956), which effectively demonstrated the role of predation in increasing benthic production.

The results of the predation-diversity experiments bear important implications in the use of diversity indices in environmental monitoring. A reduction of diversity in outfall areas has been interpreted commonly as the result of a physical degradation of the requisite environmental needs of the infauna species, whether adult or larval forms. The results of the present study clearly establish that the same effect on benthic infaunal diversities can be secondarily produced by reduced predation. If large infaunal predators are excluded from the outfall area by death or avoidance, a decrease in benthic diversities could be expected without the discharge having any detrimental effect on the infaunal species. Conversely, if benthic predators are attracted to an outfall area, e.g., seek a preferred temperature in a

thermal discharge, the benthic diversities might be expected to increase. The degree of change will be a function of the density and species of predators attracted to the discharge.

8.3.6.4 Benthic Community and Factor Analysis

Petersen's definition of a benthic community as discussed earlier is based on characterizing the samples by the first and second most abundant, of the largest and most easily recognizable species. In the present study there were no large, easily recognizable species. Lie (1968), in his Puget Sound studies, concluded that there are no definable communities in the classical sense in Puget Sound. He noted a general gradation or continuum between shallow- and deep-water infaunal assemblages. He felt that there is some possibility of distinguishing a sandy-bottom shallow-bay community based on the abundance of ostracods in these areas (*E. producta* and *carcharodonta*).

The general increase in diversity found with increasing depth of the grab samples was due to a gradual increase in amphipods of several genera and molluscs not collected in the shallow stations. The only striking change in species rank was due to absence of *Transenella* in the deep (40 and 60 ft, 12.2 and 18.3 m) grab samples and its abundance in the shallow ones (20 ft, 6.1 m). It might qualify as a separation of the two communities. On this basis, the shallow-water area might be named the *Euphilomedes-Transenella* community, and the deep-water area might be named the *Euphidomedes-Photis* community, since photids replaced *Transenella* in numerical importance at the deeper stations. These two assemblages may represent facies. Molander (1928) concluded that in certain incidences, his assemblage represented facies in Petersen's communities. He reached this conclusion from those areas where he was unable to discover the same pair of dominant species described by Petersen, and where one of the species had been replaced by a new species.

The shortcomings of community definition are obvious from the above discussion. The more promising approach lies in a statistical technique that incorporates all of the information gathered for each species in the collection. Fager's (1957) method of recurrent group analysis does not take into account information on the numerical abundance of the collected species.

Although the argument might follow that the most abundant will be the most commonly scored in a presence or absence checklist, it sacrifices the information on species rank collected in benthic studies. Fager proposed that additional statistical techniques be used on the data following recurrent group analysis so that the information on species abundance could be incorporated in the community description. An application of his method to several sets of core samples from the present study resulted in separation of only one recurrent group.

The use of factor analysis in community definition has been successfully applied, as mentioned earlier, by Cassie and Michael (1968) and Kelly and Lie (1970). The advantage of the technique is that information on the abundance of individual species is retained in the analysis. In the present study, factor analysis was clearly sensitive to the changes within species assemblages induced by crab predation. This finding demonstrates that the use of the technique should accurately respond to faunal changes that constitute new communities; and Lie (1970) proved in his studies along the Washington coast, in which he used factor analysis, that faunal changes of this sort emerged as statistical units or communities. The second conclusion is that the technique would enable, likewise, detection of minor community changes that result from the effect of waste discharge on the abundance of predators in an area.

8.3.7 Summary and Conclusions

1) This study contributes to our knowledge of the Puget Sound benthic invertebrates in the following areas: (a) a species collection from northern Puget Sound, (b) the discovery of possibly five new infauna species; one new species of ostracod for certain, (c) a two-year monthly record of the species diversity and abundances of benthic infauna at a station in Puget Sound, (d) a seasonal record of the diversity and abundances of Puget Sound invertebrate epifauna, (e) establishment of a significant relationship between infauna diversity and crab predation, and (f) demonstrated the sensitivity of factor analysis to community changes induced by predation.

2) Several new species were recorded for Puget Sound in addition to those collected by Lie (1969). It is vital to an understanding of infauna ecology to have as complete a knowledge as possible of the kinds of species present.

3) Diversity calculations were performed as a matter of record and to allow comparison in follow up studies. The loss of species composition information, however, obviously impairs the usefulness of these indices in separating faunal assemblages. A complete recolonization of the area by warm water species following thermal addition could produce exactly the same diversity indice. Factor analysis is suggested as an alternative approach.

4) Frequent infauna sampling demonstrated that changes in species diversity were reasonably minor over a two-year period. Some seasonal fluctuation was due to larval recruitment in the spring and early summer.

5) The diversity of invertebrate epifauna showed relatively little change as compared to fish diversities from the same areas (*see* section 9.0). The ability of fish to migrate to more favorable conditions would account for this difference in diversity stability.

6) An increase in crab predation was shown to increase infauna diversities. The effect was produced by the crab cropping the most abundant species. Crab predation also caused a significant decline in the infauna density.

7) Exclusion of predation (adult crabs and demersal fish) was shown to significantly reduce infauna diversities. The abundance of the dominant infauna species increased in the absence of predation.

8) The application of the statistical technique of factor analysis to the data collected in crab predation experiments demonstrated that the technique was sensitive to changes in biological interactions of the infauna community. The use of factor analysis to monitor environmental changes appears promising.

9) A warm water discharge could effect infauna diversity by attracting or repelling infauna predators in the discharge area. This result might, however, be offset by the direct effect of environmental degradation on the infauna diversities.

Appendix Table 8.A. Total number of invertebrates caught by trynet and otter trawl summed for all stations for each sampling date

Species	1970			1971							1972					Total
	8	10	12	2	3	4	6	8	10	12	1	2	4	6	8	
Cancer spp.		60	70	17	22	10		8	10	1	2	12	7	24	63	306
Cancer gracilis									9			3	2	14	4	32
Cancer magister		14	14		2	9	34	1	1		6	4	6	13	4	108
Cancer oregonensis														12	7	19
Cancer productus		39	21	11	7	8	10	7	4		5	6	22	29	17	187
Chionoecetes bairdi						1					1	6	2			10
Hyas lyratus					10	3			14	1	4	114	42	100	192	480
Lophopanopeus bellus									6	9	3	37	8			63
Pugettia gracilis							1		17			14	5	6	34	77
Pugettia pugettensis									3	7	3	17	34	21	82	167
Oregonia gracilis			10			2	3		168	28	16	273	209	125	100	934
Scyra acutifrons							3			14						17
Pugettia producta		3	3									7		6		19
Crago spp.									873		576					1,449
Crago franciscorum									510		1,319	2,306	1,513	1,213	985	7,846
Pandalus spp.			3				1				5					9
Pandalus danae									873			708	458	2,410	891	5,340
Pandalus hypsinotus				95		2	12		9		1	47	26	27	5	224
Pandalus platyceros												14		55		69
Pandalus dispar						2							101		12	115
Pandalus borealis													7	3	1	11
Pandalus goniurus									42	28		1	5		6	82
Paracrangon echinata									13	1	1	44	12	111	36	218
Spirontocaris spp.									3	92	36	64	41	46		282
Spirontocaris kincaidi									10			57	36	353	112	568
Spirontocaris lamellicornis									7	2		30	10	10	15	74
Spirontocaris groenlandica															9	9
Spirontocarid sp. 1														6		6
Spirontocarid sp. 2														13		13
Spirontocaris brevirostrus												1		29	1	31
Asteroidea	5								+	+	1					6
Heliaster sp.										4	2					6
Henricia leviuscula													1	1	1	3
Leptasterias sp.										6	6	9	7	13	14	55
Patiria miniata									1	1	2	1	1	3	3	12

Appendix Table 8.A. Total number of invertebrates caught by trynet and otter trawl summed for all stations for each sampling date - continued

Species	1970			1971							1972					Total
	8	10	12	2	3	4	6	8	10	12	1	2	4	6	8	
Pisaster sp.									2				1	2	1	6
Pisaster ochraceus									3	4	4	1			1	13
Pycnopodia helianthoides									2	1		1				4
Solaster sp.															4	4
Strongylocentrotus droebachiensis												10	2	6	10	28
Holothuroidea												15				15
Cucumaria spp.												75	11	3	75	164
Stichopus californianus							22			924		35	69	414	94	1,558
Cardium spp.											3	9	6		1	19
Pectin caurinus	1						1									2
Pectin sp.														1		1
Octopoda	2															2
Rossea sp.							1									1
Bullaria gouldiana									16	193	265	600	31		52	1,157
Polinices palida												1	1			2
Polineces (egg cases)										28	121	179	106			434
Cryptochiton stelleri													1		1	2
Metridium spp.												3	64	50	33	150
Tealia spp.															9	9
Leioptilus guerneyi												2			7	9
Mysidacea									37	2	7		3		2,422	2,481
TOTAL																24,919

9.0 SPECIES DIVERSITY OF THE MARINE FISH COMMUNITY IN NORTH SKAGIT BAY

by

Q. J. Stober, D. T. Griggs, and D. L. Mayer

9.1 INTRODUCTION

Environmental change, whether natural or man-caused, can be assessed by observation of the distribution and abundance of species within an area. Normal variation must be characterized in a variety of habitats so that natural changes, such as seasonal influx of migrants or local movements of resident species, are understood. Species-numbers diversity is usually a more sensitive and reliable index of environmental health than are individual "indicator" organisms (Wilhm, 1966). It is important to determine the pattern of diversity in time and space prior to the advent of man-induced environmental change. The response of various diversity indices to different components of the community requires the selective use of an array of indices. Since the indices are variously affected by sample size and seasonal phenomena, it is also necessary to analyze population dynamics, seasonal changes in taxa, and numbers of species and individuals.

The concept of measuring species-numbers diversity as a means of analyzing estuarine fish fauna has been applied by Dahlberg and Odum (1970) and McErlean et al. (1971). Indices of diversity of fish species were used by Bechtel and Copeland (1970) to show how adverse water quality eliminated certain species and reduced the relative abundance of others in a heavily polluted estuary. The objective of this study was to establish baseline information on the influence of seasonal changes on the taxa, abundance, biomass, and population dynamics of the marine fish community in the bay areas surrounding Kiket Island.

9.2 MATERIALS AND METHODS

9.2.1 Sampling Design

A comprehensive bimonthly sampling program was developed for procurement of baseline data on the influence of seasonal changes in taxa, abundance, biomass, and size frequency of demersal and pelagic fish populations.

Sampling was conducted during two years from August 1970 to August 1972 in three specific areas surrounding Kiket Island, Hope Island Bay (area 1), the area west of Skagit Island, designated Skagit Bay-West (area 2), and Similk Bay (area 3), Fig. 9-1. Three benthic environments were sampled within each bay area with three different gears: (1) the midchannel (deep scoured area) from 9.1-29.2 m deep (30-90 ft) was sampled with an otter trawl; (2) shallow (6.0 m, 20 ft deep) shelf areas were sampled with a trynet; and (3) the intertidal within 100 ft of the water line was sampled with a beach seine. The pelagic area was sampled at three depths with a midwater trawl; however, the results of more intensive midwater sampling are presented in Section 5.0 Salmonid Migration. Since each gear type has specific sampling characteristics several gear were used in order to sample more habitats and reduce the dependence of an analysis based on the pecularities of a single gear or habitat.

9.2.1.1 Otter Trawling

Three trawl stations were established in midchannel areas surrounding Kiket Island (Fig. 9-1). Hope Island Bay was sampled on a transect following the channel between Tosi Point and Skagit Island. The depth averaged 27.4 m (90 ft), and the bottom was largely rock and mud. Skagit Bay-West was sampled on a transect extending northwest from Skagit Island toward Dewey Beach. Average depth was 29.2 m (96 ft), and the bottom was coarse sand and gravel. Similk Bay was surveyed along the center. Maximum average depth was 5.5 m (18 ft), and the bottom was soft mud. Tidal currents were at maximum strength at station 2 nearest the east end of Deception Pass, of medium strength at station 1, and of least influence at station 3, especially in the upper extremity of Similk Bay.

All stations were sampled from the R.V. *Commando* with a 3.0-m x 6.0-m (10-ft x 20-ft) trawl with 38-mm (1-1/2-inch) mesh in the cod end. All trawls were 10 min in duration, at a towing speed of 11.1 km/hr (6 knots). Exceptions to the above procedures occurred from August 1970 to October 1971 when trawling times varied from 10-20 min. The April 1971 sample was taken with a net with 7.6-cm (3-inch) mesh in the cod end. During the period August 1970 to March 1971 trawls were conducted during day and night for the

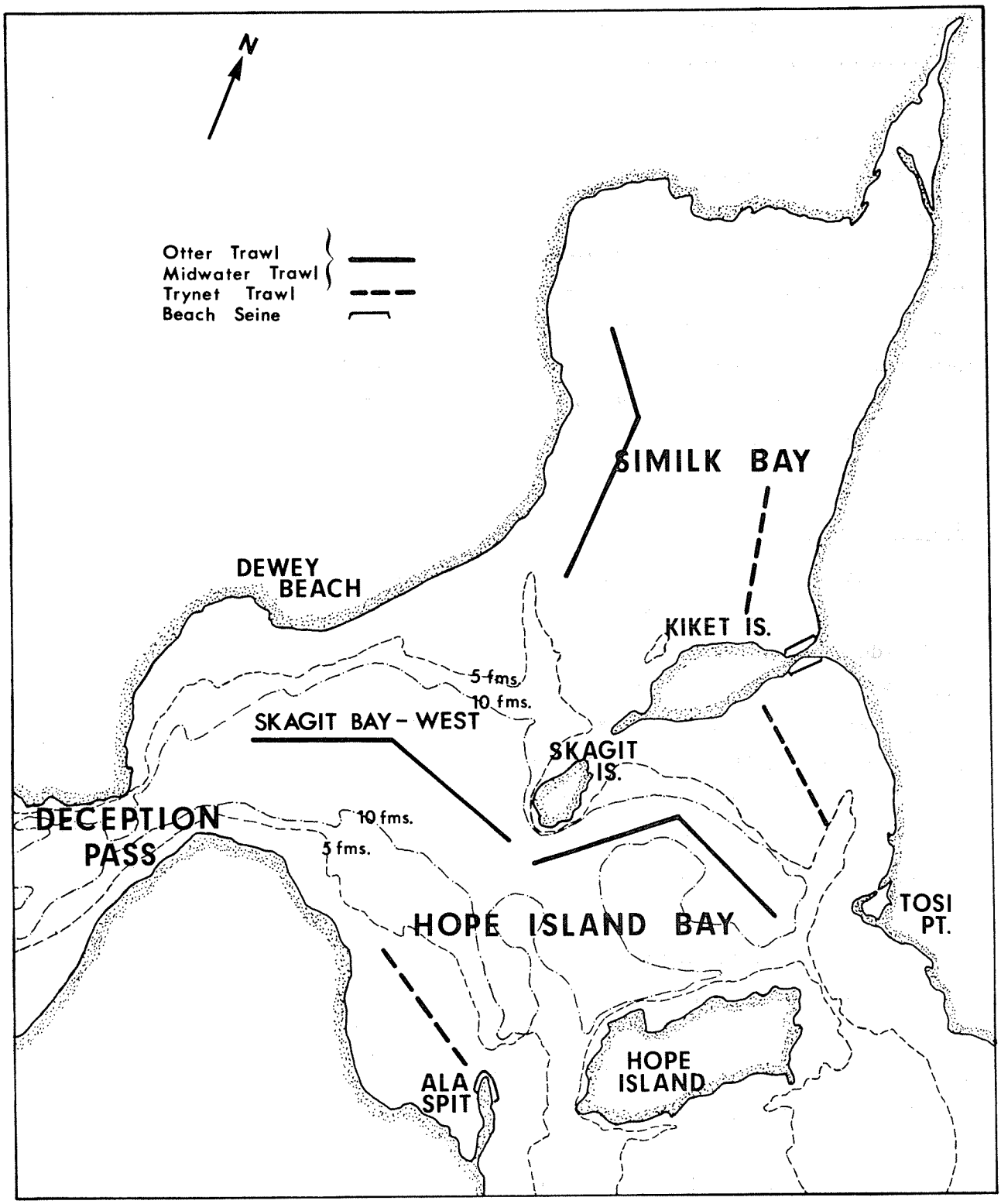

Fig. 9-1. Kiket Island and surrounding bays with marine fish sampling stations indicated for otter trawl, midwater trawl, trynet, and beach seine.

purpose of ascertaining differences in efficiency. No obvious difference was apparent, and a daylight sampling schedule was followed thereafter.

9.2.1.2 Trynetting

Two trynet trawl stations were established in August 1970 on shelves approximately 6.0 m (20 ft) in depth. The first station was located in Hope Island Bay and the second one north of Kiket Island in Similk Bay. A third station north of Ala Spit in Skagit Bay-West was established in October 1971 (Fig. 9-1) at a mean depth of 5.5 m (18 ft). Two replicate 10-min trawls were made in each area from a 5.5-m (18-ft) skiff with a 0.9-m x 3.0-m (3 x 10-ft) trynet (otter trawl) with 6-mm (0.25-inch) mesh in the cod end. Trawling speed was about 5.5 km/hr (3 knots) at 1,400 rpms.

9.2.1.3 Beach Seining

Three beach seine stations were established in October 1971. One station was located on the south side of Kiket Island, the second on the northwest side of Ala Spit, and the third on the north side of Kiket Island (Fig. 9-1). Three replicate hauls were made at each station with the seine set by means of a 5.5-m (18-ft) skiff. The seine was 30.5 m (100 ft) in length and 1.8 m (6 ft) wide in the center and tapered to 1.2 m (4 ft) wide at both ends. It was constructed of knotless nylon with a mesh size of 38 mm (1-1/2 inch) in the leads and 6 mm (1/4 inch) in the bunt. Attached to each end of the seine were 30-m (100-ft) lines to facilitate sampling.

9.2.1.4 Midwater Trawling

Samples were collected in the water column at the otter trawl stations (Fig. 9-1). Hauls of 10-min duration were made from aboard the R.V. *Commando* at the surface, 0-3.0 m (0-10 ft), and at depths of 9.1 m (30 ft) and 18.2 m (60 ft) at a speed of 11.1 km/hr (6 knots). All midwater trawl samples were collected at night. A Kodiak townet with 6-mm (1/4-inch) mesh (stretched) in the cod end was used with otter boards.

9.2.2 Sample Processing

Samples taken by all the above methods were identified to species, counted, and measured in length to the nearest millimeter. Weights were taken to the nearest gram or ounce with the exception of samples taken from August 1970 to October 1971.

9.2.3 Calculation of Diversity Indices

Three diversity indices were calculated. The Shannon-Wiener function is

$$H' = -\Sigma\, p_i \log_e p_i$$

where p_i is the proportion of individuals in the i^{th} species (Pielou, 1966). H' is the diversity of the entire population, a value which cannot be determined for the fish population of an estuary. This formula was modified so that it could be applied to such populations. Shannon-Wiener diversity was estimated by: $H'' = -\Sigma \frac{N_i}{N} \log_e \frac{N_i}{N}$, where N_i is the number or weight of individuals in the i^{th} species of the sample and N is the total number of individuals in the sample (Bechtel and Copeland, 1970). H''_N is the diversity calculated on numbers of individuals. H''_w can be obtained by substituting biomass for numbers and is useful when considering the weight structure of a community with species with a large weight difference. It shows more closely the distribution of biomass among the species (Wilhm, 1967). H''_N and H''_w increase when the number of species captured and/or the relative species abundance or biomass increase. Two other indices were selected for the two components "species richness" and "evenness," since they may react differently to various environmental stresses.

The species richness component of diversity was evaluated with the following formula:

$$d = \frac{S-1}{\log_e N},$$

where S is the number of species and N is the number of individuals in the

sample. This index, developed by Margalef (1968), is sensitive to changes in the number of species within a community.

For assessment of the relative species abundance the "evenness" index of Pielou (1966) was used:

$$J = H''_n/\log S,$$

where H''_n is the Shannon index and log S is the number of species. "J" was shown to be affected by seasonal changes in distribution of individuals among species (Dahlberg and Odum, 1970).

All calculations were based on the use of natural logarithms.

Wilhm (1970) and Odum (1971) suggested that only asymptotic diversity indices be reported and that the necessary sample size can be achieved by taking replicate samples. In practice this is difficult to achieve because of rapid changes in the species abundance and reduction of the population where samples are not replaced. Otter trawl sampling was restricted because of the small size of the study area and because inordinately large numbers of replicates were necessary so that asymptotic values could be produced for the species richness index (d).

Rank correlation of species was evaluated through the following formula:

$$r_s = 1 - \frac{6\Sigma d^2}{n(n^2 - 1)},$$

where r_s is the rank correlation coefficient, d is the difference between rankings, and n is the number of items ranked. The rank correlation coefficient (r_s) ranges from -1 (complete discordance) to +1 (complete agreement) (Snedecor and Cochran, 1968 p. 194).

Concordance, the measure of consistency of rank relationships between species for a given number of samples, was calculated through the following formula:

$$W = \frac{12\ S}{m^2 n\ (n^2 - 1) - m\Sigma_t\ (t^2 - 1)},$$

where W is the coefficient of concordance, S is the sum of the squares of the deviations of these sums from their means, n is the number of items ranked, t is the number of ties, and m the number of samples ranked. The range of W is from 0 (no consistent rank relationship) to 1 (complete consistency of rank relationships) (Fager, 1957).

Rank correlation and concordance were calculated for catches of otter trawl and trynet from samples collected during the period October 1971 - August 1972. The ten most abundant species were ranked according to their numerical abundance within each sample with the exception that samples from replicate hauls of the trynet were pooled for each area and then ranked. Rank correlation of replicate hauls by trynet was done within each area.

9.3 RESULTS

9.3.1 Total Catch

A total of 68,725 fish was captured comprising 86 known species, 1 hybrid, and 28 families (Table 9-1). Seventy-seven species are entirely marine and nine species, in the families of Salmonidae, Gasterosteidae, and Petromyzontidae, occur in freshwater during certain periods in their life cycles. Maximum numbers of individuals occurred during the August and October sampling in both years, whereas a maximum number of species occurred during the January sampling in 1972. The percentages of the total catch by otter trawl, trynet, beach seine, and midwater trawl were 88.9, 2.2, 4.4, and 4.5 per cent, respectively.

When the species were ranked by number of individuals, it was found that 89 per cent of the total catch consisted of 14 species in 10 families. These species and their respective percentages of the catch were Pacific tomcod (*Microgadus proximus*) 28.6 per cent, shiner seaperch (*Cymatogaster aggregata*) 16.3 per cent, English sole (*Parophrys vetulus*) 12.4 per cent, herring (*Clupea harengus pallasi*) 9.9 per cent, spiny dogfish (*Squalus acanthias*) 5.4 per cent, longfin smelt (*Spirinchus thaleichthys*) 3.8 per cent, pile perch (*Rhacochilus vacca*) 2.8 per cent, staghorn sculpin (*Leptocottus armatus*) 2.6 per cent, butter sole (*Isopsetta isolepis*) 2.5 per cent, rock sole (*Lepidopsetta bilineata*) 2.0 per cent, surf smelt (*Hypomesus*

Table 9-1. Total catch by species for all stations and gear by date

	1970			1971							1972					Totals
	Aug	Oct	Dec	Feb	Mar	Apr	Jun	Aug	Oct	Dec	Jan	Feb	Apr	Jun	Aug	
Petromyzontidae								1								1
Squalidae																
Squalus acanthias	62	185	374	168	237	29	216	232	202	343	412	169	636	182	252	3,699
Rajidae	18	11	19	15	2	2										67
Raja binoculata				1			7	2	11	19	11	9	11	16	12	99
Chimaeridae																
Hydrolagus colliei		2	4	6	3	1	63		1	20	26	4	1	4	35	170
Clupeidae																
Clupea harengus pallasi	141	4	518	589	308	98	36	253	1,505	709	570	228	244	317	1,307	6,827
Engraulidae																
Engraulis mordax										6	1	1	2			10
Salmonidae																
Oncorhynchus gorbuscha													81	72		153
Oncorhynchus keta						3	3	1					45	104		156
Oncorhynchus kisutch														8		8
Oncorhynchus tshawytscha	1						2	6	1				26	49	41	126
Salmo clarki													4	1		5
Salmo gairdnerii															1	1
Salvelinus malma													3	1	2	6
Osmeridae	6		10	20				25	18	168	65	144			31	487
Hypomesus pretiosus	1	194	189	147	16	15	9	3	13	7	2		163	71	24	854
Mallotus villosus		3								1			2			6
Spirinchus thaleichthys			25	1	35	14	5	20	447	139	260	116	981	67	501	2,611
Thaleichthys pacificus											1					1
Batrachoididae																
Porichthys notatus	1	4	6			4		5	16	9	5		1	2	4	57
Gadidae																
Gadus macrocephalus	13	27	14	2	2	6	2	2	2		1	4		1		76
Merluccius productus		5		2						1	1				10	19
Microgadus proximus	760	1,521	981	338	395	167	485	1,132	3,807	1,736	2,247	1,085	2,202	316	2,452	19,624
Theragra chalcogramma	1	2	9	10	71		1	1	1	3	2		2			103

Table 9-1. Total catch by species for all stations and gear by date (Continued)

	1970			1971							1972					Totals
	Aug	Oct	Dec	Feb	Mar	Apr	Jun	Aug	Oct	Dec	Jan	Feb	Apr	Jun	Aug	
Zoarcidae	25	95	15	9	2	1	12	438					1	9		607
Aprodon cortezianus													1	63	472	536
Lycodes brevipes							3		222	135	19	20	1	37	139	576
Lycodes diapterus									267	6						273
Lycodes palearis										1	1					2
Lycodopsis pacifica							75		1	267	45	2	1		3	394
Gasterosteidae																
Gasterosteus aculeatus	16		1		1	3		216	33	2	9	24	3	6	74	388
Aulorhynchus flavidus	14		6	2						2	3			3		30
Syngnathidae																
Syngnathus griseolineatus		2				3							2			7
Embiotocidae																
Cymatogaster aggregata	37	920	35			8	1	2,587	2,500	2,305	1,029	294	1,223	46	222	11,207
Embiotoca lateralis							2		5	50	8				4	69
Rhacochilus vacca		291	22			4			310	964	192	27	88		1	1,899
Trichondontidae																
Trichodon trichodon								12	1							13
Bathymasteridae																
Ronquilus jordani							2	2			3	3				10
Stichaeidae			1		2											3
Lumpenus sagitta	5	1				1	157	46	17		2		1	217	208	655
Pholidae									1							1
Pholis laeta									5					2		7
Pholis ornata							1	1	3	1				81		87
Anarrhichadidae																
Anarrhichthys ocellatus		1														1
Ammodytidae																
Ammodytes hexapterus	1	1			1					10			16	62	15	106

Table 9-1. Total catch by species for all stations and gear by date (Continued)

	1970			1971							1972					Totals
	Aug	Oct	Dec	Feb	Mar	Apr	Jun	Aug	Oct	Dec	Jan	Feb	Apr	Jun	Aug	
Gobiidae									1							1
Scorpaenidae		4	3		4	6		1	3	5		1	1	28	1	57
Sebastes caurinus						1	2	25	1	5	5	17	4		5	65
Sebastes maliger						1	2									3
Sebastes melanops											9	2		1		12
Sebastes ruberrimus	1															1
Hexagrammidae	1	1		5	17							4	9			37
Hexagrammos decagrammus							1	1	1			5				8
Hexagrammos stelleri	1	1	3	7									11		3	26
Cottidae		580	33	4	1	1		1	8			1	29			658
Artedius fenestralis											3	1		1		5
Artedius lateralis		1														1
Artedius harringtoni												1	1			2
Blepsias cirrhosus			1									1	1			3
Chitonotus pugetensis			52													52
Clinocottus acuticeps										1						1
Dasycottus setiger							11	6	9	5	6	3	7	12	10	69
Enophrys bison			3			2				1	6			1	1	14
Gilbertidia sigalutes				31							46	83	4	19	1	184
Hemilepidotus hemilepidotus		4			19		1	1		2						27
Icelinus borealis	1						1					6		3		11
Leptocottus armatus	72	21	297	23	101	1	2	9	194	189	211	44	121	428	69	1,782
Myoxocephalus polyacantho-ephalus										6	3	2	2	1	1	25
Nautichthys oculofasciatus											1					1
Oligocottus maculosus														59	2	61
Psychrolutes paradoxus				1		1	60	3	14	7	3	2			32	123
Radulinus asprellus							1									1
Scorpaenichthys marmoratus		24		10		2	1									37
Triglops pingeli							4									4

Table 9-1. Total catch by species for all stations and gear by date (Continued)

	1970			1971							1972					Totals
	Aug	Oct	Dec	Feb	Mar	Apr	Jun	Aug	Oct	Dec	Jan	Feb	Apr	Jun	Aug	
Agonidae		4	20	6					1	17	3	1	3			55
Agonus acipenserinus	4	5			6		5	3	15	2	22	12	4	6	16	100
Anoplagonus inermis													1	1		2
Asterotheca infraspinata											4					4
Odontopyxis trispinosa														1		1
Pallasina barbata										1	1	4	1			7
Xeneretmus latifrons													1			1
Cyclopteridae		16	21	86						11	16					150
Eumicrotremus orbis				1			2		2	2	1	1		3		12
Liparis cyclopus									2							2
Liparis dennyi									13	6						19
Liparis fucensis									1		1	13	2	1		18
Liparis pulchellus								2	8		1	4		1		16
Bothidae	1						3		3		3			1		11
Citharichthys sordidus	4	11	7	8	5					1	1		4		1	42
Pleuronectidae																
Atheresthes stomias			6	2	1		1	6	2			2		2		22
Glyptocephalus zachirus	6	3	21	13	3	3	15	6	57	47	33	15	39	20	53	334
Hippoglossoides elassodon	7	9			2	1	14	22	24	4	75	15	12	2	38	225
Isopsetta isolepis	11	46	645	68	67	12	16	3	18	68	426	107	181	13	13	1,694
Lepidopsetta bilineata	86	93	113	31	57	69	134	135	138	155	61	54	82	101	70	1,379
Lysopsetta exilis					1	3										4
Microstomus pacificus	14	15	115	10	4	2	26	45	40	6	7	7	6	13	22	332
Parophrys vetulus	379	779	469	158	404	56	131	129	1,591	431	1,510	460	1,147	170	687	8,501
Platichthys stellatus	25	6	12	2	5	6	3	2	40	19	17	36	24	103	37	337
Psettichthys melanostictus	5	13	35	9	4		5	7	9	12	2	13	8	3	9	134
P.V. x P.S. Hybrid		1	9						2		1					13

pretiosus) 1.2 per cent, snake prickleback (*Lumpenus sagitta*) 1.0 per cent, shortfin eelpout (*Lycodes brevipes*) 0.8 per cent, and bigfin eelpout (*Aprodon cortezianus*) 0.8 per cent.

Dogfish and staghorn sculpin are the major predators of fish listed above and were present throughout the year. Seasonal changes in abundance were extreme for many of the above species. Juvenile Pacific tomcod, herring, and shiner seaperch were most abundant between June and October. Adult spawning tomcod were captured in large numbers with the otter trawl in Skagit Bay-West in March. Adult herring were found to be most numerous in the winter months prior to spawning in January-March and May. Snake prickleback and shortfin eelpout were captured in large numbers in June-August and bigfin eelpout in October-December. Anchovies (*Engraulis mordax*) appeared only during the winter and early spring months. The seasonality of the anadromous salmonids was discussed previously in Section 5.0. The two predominant species of smelt (surf and longfin) were most abundant during the fall-winter months. The maximum number of stickleback (*Gasterosteus aculeatus*) occurred in August in both years. The family Pleuronectidae was consistently represented throughout both annual cycles by seven species.

When the species were ranked by biomass, 89.1 per cent of the catch was composed of nine species representing a total of six families. These groups and their respective percentages of the catch were dogfish 39.9 per cent, Pacific tomcod 15.3 per cent, English sole 13.0 per cent, big skate 9.8 per cent, rock sole 4.5 per cent, shiner seaperch 2.3 per cent, butter sole 1.7 per cent, copper rockfish 1.3 per cent, and pile perch 1.3 per cent.

9.3.2 Otter Trawl Catch

The bimonthly calculated diversity indices of H''_n, H''_w, J, and d are compared with numbers of species and sample sizes for the deep areas sampled by otter trawl in Fig. 9-2. Hope Island Bay had the most consistent H''_n, H''_w, J, and d indices. With Skagit Bay-West H''_n, H''_w, and J varied moderately, following a similar pattern, whereas d was greatest and had the largest fluctuations. In Similk Bay H''_n, J, and d exhibited large variations and low values, whereas H''_w was more uniform. Analysis of variance indicated a significant difference between otter trawl stations for H''_n

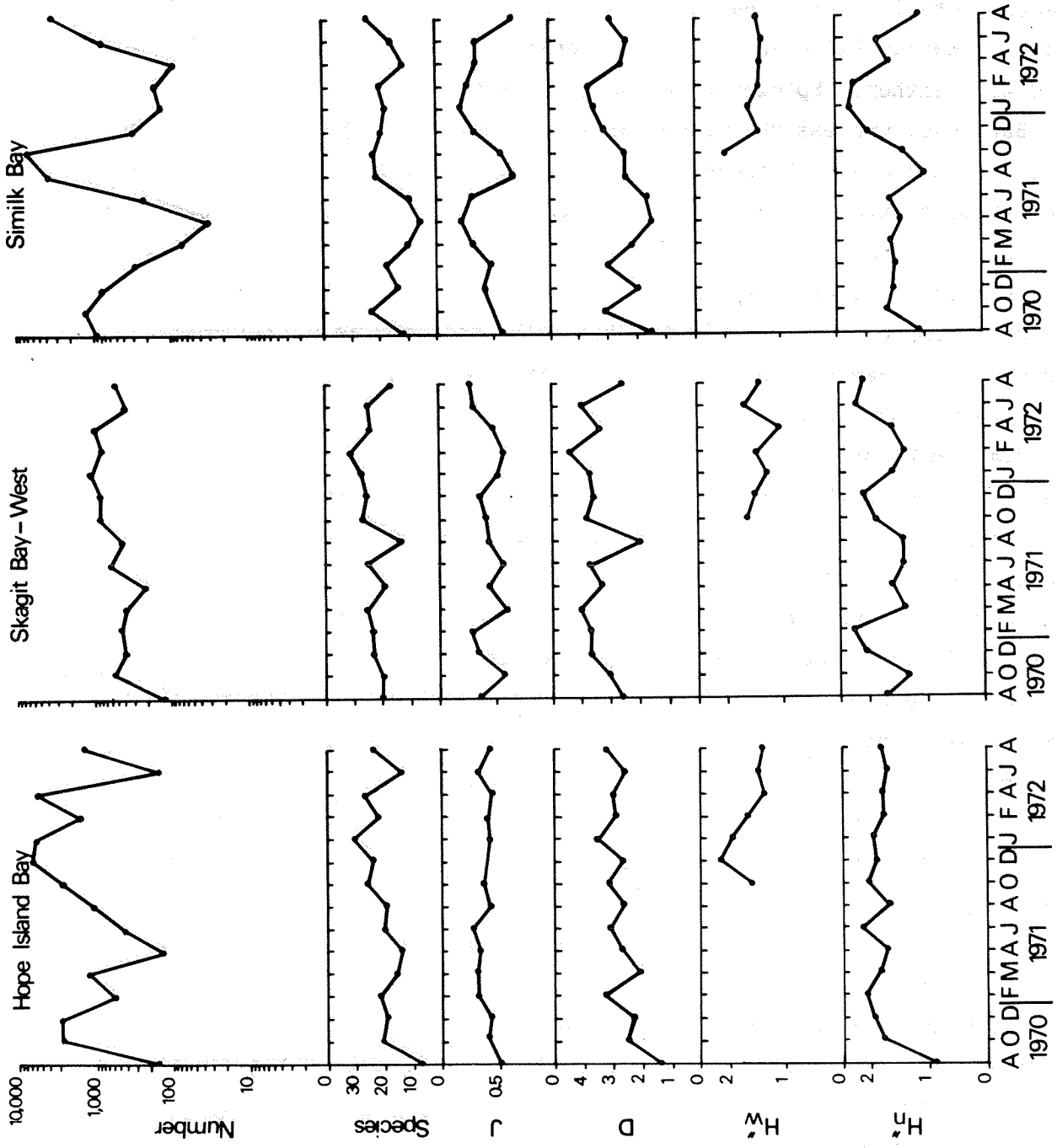

Fig. 9-2. Bimonthly calculated diversity indices of H", H'_n, H'_w, J, and d compared with numbers of species and sample sizes for deep areas samples by otter trawl.

(0.05) and d (0.01) in 1971 and for d (0.05) in 1972 (Table 9-2). Rank correlations for the ten most abundant species between stations for each month were generally nonsignificant and little correlated (Table 9-3). Multiple range tests indicated that H''_n values for Hope Island Bay and Similk Bay were significantly different and that Skagit Bay-West could be homogeneously grouped with either. Species richness (d) was significantly greater (0.01) in Skagit Bay-West, whereas the number of individuals was significantly lower (0.05). H''_w and J were homogeneous during the entire study when compared on a month or station basis. A significant difference (0.01) was found between years (October 1970 - August 1971) and (October 1971 - August 1972) for the number of species captured. This resulted due to an increased proficiency in sample processing in the field the second year.

Hope Island Bay was shown to have an intermediate number of species among which the number of individuals was more evenly distributed than other otter trawl areas. Skagit Bay-West had a significantly larger number of species, many of which could be considered rare in North Skagit Bay, as well as large numbers of individuals of the most abundant species. Similk Bay samples had the lowest diversity, fewer species, and large numbers of individuals of the most abundant species probably due to the shallow depth. This area had large numbers of juvenile Pacific tomcod and shiner seaperch, the two most abundant species during summer and fall.

No significant differences were found between months for H''_n , H''_w , J, d, number of species, or specimens. Seasonal changes were not significant because the influence of the Skagit River and other environmental changes had a negligible effect upon the deep-water sampling areas in Skagit Bay-West and Hope Island Bay.

The rank relationships between species (concordance) were inversely related for each area during October 1971 - August 1972, but this relationship was not statistically significant (Table 9-4).

Statistical comparisons of the diversity indices calculated for the three other trawl sampling stations indicated a significantly larger number of species was consistently captured in the area designated Skagit Bay-West, while in Hope Island Bay the number of species was reduced; however, the number of individuals was more evenly distributed. Similk Bay had the

Table 9-2. Results of analysis of variance and multiple range tests of diversity indices, number of species and specimens by station, year, month, and replicate for each gear type

	H''_n	H''_w[1]	J	d	Number of species	Number of specimens
Otter trawl						
Years 10/70-8/71 10/71-8/72	1.471	-	.004	4.104	6.612*	3.930
Months 10/70-8/72	.587	.685	1.188	.154	.202	.262
Stations 10/70-8/71	4.295*	-	.627	6.174**	2.669	1.326
Trynet						
Years 9/70-10/71 12/71-8/72	.005	-	.200	.394	.512	1.344
Months 9/70-8/72	3.212**	-	.728	2.160*	3.781**	5.474**
Months 10/71-8/72	2.224	-	.677	.401	1.784	633.150**
Stations 9/70-8/72	.175	1.106	.006	5.854	4.00	.615
Stations 10/71-8/72	.803	-	1.920	4.019	8.480	.003
Replicates	2.372	1.001	.416	.964	.278	1.513
Beach seine						
All areas						
Months 10/71-8/72	.378	.814	.292	.441	.585	.810
Months area 1	2.417	3.272*	.638	5.386**	11.585**	1.453
Months area 2	3.235*	1.782	2.549	2.839	4.437*	.908
Months area 3	5.180**	7.697**	2.203	6.147**	17.969**	4.437*
Stations 10/71-8/72	1340.909**	38.906*	12.192	23.112*	53.003*	7.473
Replicates	.024	.245	1.216	1.043	1.093	.977
Midwater trawl						
Months 10/71-8/72	1.710	-	.515	1.377	3.234*	1.488
Stations 10/71-8/72	.872	-	1.320	.386	1.496	1.727

*Significant .05 level.
**Significant .01 level.
[1]Available only 10/71-8/72.

Table 9-3. Rank correlation for the ten most abundant species between stations by month for otter trawl and trynet

Areas	10/71	12/71	1/72	2/72	4/72	6/72	8/72
Otter trawl							
1-2	.8181**	.3575	.3696	.3212	.5151	.6666*	.8303**
1-3	.4424	-.2484	.1151	.4606	.1151	.4000	.4787
2-3	.3212	.6121	.3090	.4181	.2727	.5757	.5636
Trynet							
1-2	-.0969	.9090**	.5090	.9575**	1.000**	.4060	.5272
1-3	.8969**	.9696**	.9454**	.8181**	.9878**	.8969**	.9090**
2-3	.1636	.8787**	.5030	.9454**	.9878**	.3151	.7272*
Replicates							
1	.9575**	.8000**	.8181**	.9939**	1.0000**	.9393**	-
2	.7272*	.8242**	.7575*	.9454**	1.0000**	1.0000**	.9454*
3	.9818**	.9878**	.8060**	-	1.0000**	.8848**	.3272

*Significant .05 level.
**Significant .01 level.

Table 9-4. Concordance coefficients (w) and F-ratios for otter trawl and trynet samples by area

Areas	Coefficient	F ratio
Otter trawl	w	
1	.0684	.4408
2	.0120	.0732
3	.0361	.2248
Trynet	w	
1	.4036	4.060**
2	.4832	5.610**
3	.4270	4.471**

*Significant .05 level.
**Significant .01 level.

lowest diversity with fewer species and large numbers of individuals. Pacific tomcod and shiner seaperch juveniles were most abundant during August and October. Seasonal changes in diversity were not significant due to the negligible effect of the Skagit River on the water quality in the deep sampling areas in Skagit Bay-West and Hope Island Bay; however, this was not the case in Similk Bay.

9.3.3 Some Effects of Life History on Sample Diversity

The life histories of Pacific tomcod and shiner seaperch altered the sample diversity during certain periods of their life cycles. Large numbers of spawning tomcod in Skagit Bay-West reduced the J and H''_n indices. After hatching, tomcod moved into bays where they became increasingly available to the catch. The length-frequency distribution of tomcod in catches is shown in Table 9-5. Tomcod composed up to 75 per cent of the catch in Similk Bay in August, reducing the J and H''_n indices.

Shiner seaperch were captured in deep water (27.4 m) (90 ft) in Hope Island Bay and Skagit Bay-West during the winter months, but they were found near the beach during the summer months. Shiner seaperch are born as the adults begin inshore movement from April to July. This phenomenon was also reported by Clemens and Wilby (1961). The movement of shiner seaperch was not indicated by diversity indices because of coincidence with other factors of greater magnitude. The main factor is the recruitment of large numbers of new individuals of predominant species to the community. Shiner seaperch increased in availability to the catch from June to October in shallow areas, especially Similk Bay during the period of sampling and composed up to 48 per cent of the catch in August and October.

Shiner seaperch and Pacific tomcod increased in abundance during the summer months and composed 90 per cent of the catch in Similk Bay in August 1971, and thus reduced the H''_n and J indices.

English sole, the third most abundant species did not induce extensive cyclic changes in the diversity indices because it was uniformly abundant during the study period. The length-frequency distribution of English sole caught by otter trawl during the sampling period is shown in Table 9-6. A seasonal inshore migration of large numbers of juveniles of this species was not apparent.

Table 9-5. Length-frequency distribution of tomcod (*Microgadus proximus*) from otter trawl catches

mm	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
8/70																		
10/70		2	1	14	5	2	1	29	47	27	32	27	13	3	1			
12/70		2	18	29	29	14	5	44	190	249	145	124	94	33	7			
2/71	1	1	32	35	32	19	12	12	60	110	64	34	30	10	3			
3/71		1	10	31	48	36	9	37	200	418	276	216	110	27				
4/71					3	1		2	31	59	51	67	48	22	6			
6/71				8	38	46	23	8	48	64	55	25	11	7		2		
8/71	46	135	96	8		9	47	16	16	22	24	15	7	1				
10/71	3	73	195	47	34	29	31	53	48	43	49	49	32	16	25	8	5	
12/71		24	32	35	10	4		5	30	11	11	13	14	1				
1/72		1	50	146	110	31	2	8	23	21	27	29	31	11	8	2		
2/72		2	14	27	34	12	1	5	13	26	16	31	29	9	2	2		
4/72			29	79	57	30	2	5	14	23	23	30	19	7	3	1		
6/72			2	31	72	65	16	2	9	30	24	26	24	5	3			
8/72	1	7	12	1	20	188	334	137	22	29	40	40	41	15	7			

Table 9-6. Length-frequency distribution of English sole (*Parophrys vetulus*) from otter trawl catches

mm	70	90	110	130	150	170	190	210	230	250	270	290	310	330	350	370	390	410	430	450	470	490
8/70	2	4	4	28	58	20	12	6	13	21	34	33	26	33	24	8	8	6		1		
10/70	7	22	19	31	21	45	26	31	22	9	4	15	8	3	4	2	2					
12/70	1	14	52	116	102	98	66	27	28	14	10	14	4		1							
2/71		3	11	28	66	52	36	24	8	14	10	3	1									
3/71		22	57	112	98	87	54	13	9	5	2	4	5	4	3	5	2	1	1			
4/71					1	1	7	1	6	11	8	12	13	7	17	6	4		1	1		
6/71					3	1	4	6	2	5	1	8	10	12	9	12	11	3	2	3		1
8/71		1	3	1		1	6	2	12	7	13	7	9	16	9	9	3	2		1		
10/71	5	2	26	88	54	23	37	50	29	42	37	28	30	25	22	12	5	4	1			1
12/71	1	2	3	4		6	3	21	116	30	16	13	7	9	12	12	4	3				
1/72	7	20	28	55	87	65	25	55	86	55	22	14	5	4	2	4				1		
2/72	5	3	11	29	53	55	22	13	31	10	6	3									1	
4/72				1	7	17	6	12	46	35	19	10	24	16	8	6	4	4	1			
6/72		1		3	4	10	4	1	2	5	3	5	2	8	9	3	9	6	3	1		
8/72		1	20	16	12	14	11	17	12	26	55	98	89	89	69	49	27	19	9	2	1	1

9.3.4 Trynet Catch

The bimonthly calculated diversity indices of H''_n, H''_w, J, and d are compared with the numbers of species and specimens for trynet samples from the shallow shelf areas in Hope Island and Similk Bays in Fig. 9-3. Skagit Bay-West appeared to have lower diversities and smaller numbers of species and individuals compared to Hope Island and Similk Bays.

A factorial analysis of variance of trynet samples indicated no significant differences between areas or replicates within areas for H''_n, H''_w, J, d, and the associated parameters, numbers of species and specimens, Table 9-2. There was no significant difference found between years.

Rank correlations of the numbers of individuals per species for the ten most abundant species between trynet areas indicated that Hope Island and Similk Bays were highly correlated (.01) by month during the second year of the study (October 1971 - August 1972) (Table 9-3). In contrast Skagit Bay-West had a significantly different sequence of ranks when compared with Similk and Hope Island Bays by months. Thus, there were some differences between trynet areas that diversity indices could not detect. Catches from replicate hauls by trynet for each area were tested by rank correlation and were found significantly correlated (.05) during October 1971 - August 1972 indicating the 10 most abundant species reoccurred in samples.

April generally had the lowest calculated diversity and August had the highest (Fig. 9-3). Multiple range tests comparing months indicated that January-April samples had significantly lower (.05) H''_n, and d values and significantly smaller numbers of species and specimens (.05), Table 9-2. The "evenness" index, J, was not statistically significant when analyzed by month.

Water temperature and salinity reached the annual minima during the period January through April coinciding with seasonal freshwater runoff indicating a relationship between changes in diversity and water quality conditions in the shallow areas sampled with the trynet. The rank relationships between species (concordances) were not constant for each area during October 1971 - August 1972 (Table 9-4); it would appear that the number of individuals changed in response to seasonal and/or biological factors and that the change was not proportional for all species in a given area.

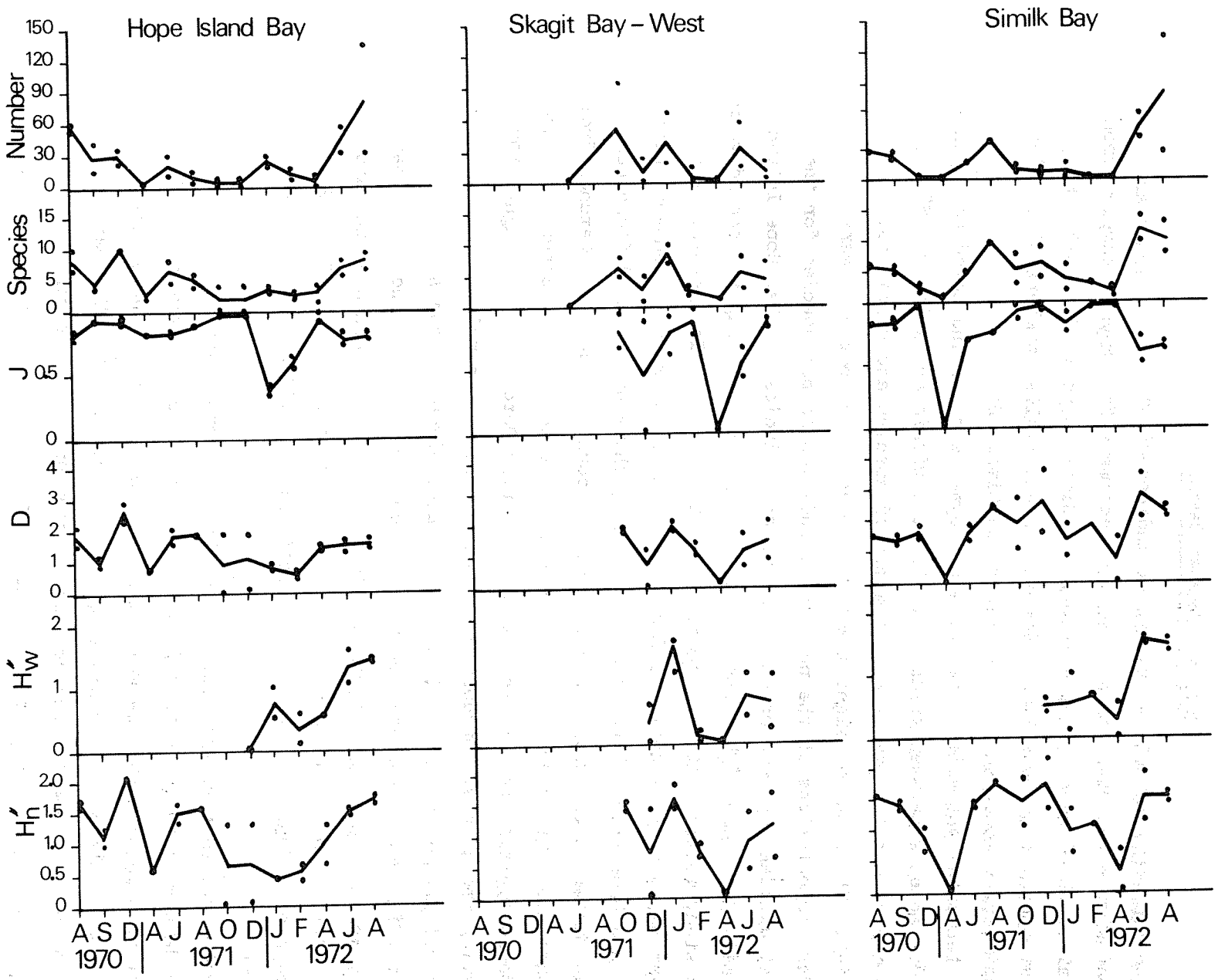

Fig. 9-3. Bimonthly calculated diversity indices of H''_n, H''_w, J, and d compared with numbers of species and sample sizes for shallow shelf areas samples by trynet.

9.3.5 Beach Seine Catch

The bimonthly calculated diversity indices of H''_n, H''_w, J, and d are compared with the associated parameters, numbers of species and individuals, for beach seine samples taken from the three bay area beaches in Fig. 9-4. Skagit Bay-West appeared to have lower diversities and smaller numbers of species and specimens than Similk and Hope Island Bays. Factorial analysis of variance indicated that there were significant differences between stations for H''_n (.01), H''_w (.05), d (.05), and the number of species (.05) (Table 9-2.)

Skagit Bay-West had lower H''_n, H''_w, and d indices and a lower number of species. The sampling station in Skagit Bay-West had a steep, scoured, sandy beach that was difficult to seine during the high tides, whereas Hope Island Bay and Similk Bay had flat sand or cobble beaches that could be sampled with a more consistent efficiency at any tide level. The above premise was partially justified by examination of the field data which indicated that beach seine samples taken in Skagit Bay-West during low tides were comparable to those of the other stations.

Differences between samples from replicate hauls within each area were found to be nonsignificant. J was also nonsignificant when analyzed by station or month. Analysis of variance for each area revealed significant differences between months for: H''_w (.05), d (.01), and number of species (.01) from Hope Island Bay, H''_n (.05), and number of species (.05) from Skagit Bay-West, and H''_n (.01), H''_w (.01), d (.01), number of species (.01) and the number of individuals (.05) from Similk Bay, Table 9-2. Months were compared in a multiple range test, and it was found that diversity and the associated parameters were generally lower (.05) from December through April; this period corresponds to the period of low temperature and salinity and freshwater runoff in the Bay areas sampled and agrees with the results of the trynet sampling.

The seasonality observed for trynet and beach seine indices was similar to the findings of Bechtel and Copeland (1970) who found, using H", that significantly lower diversities were recorded in winter and spring, whereas the highest diversities were recorded in the fall. In Dahlberg and Odum's (1970) study area diversities were low from January to March and in

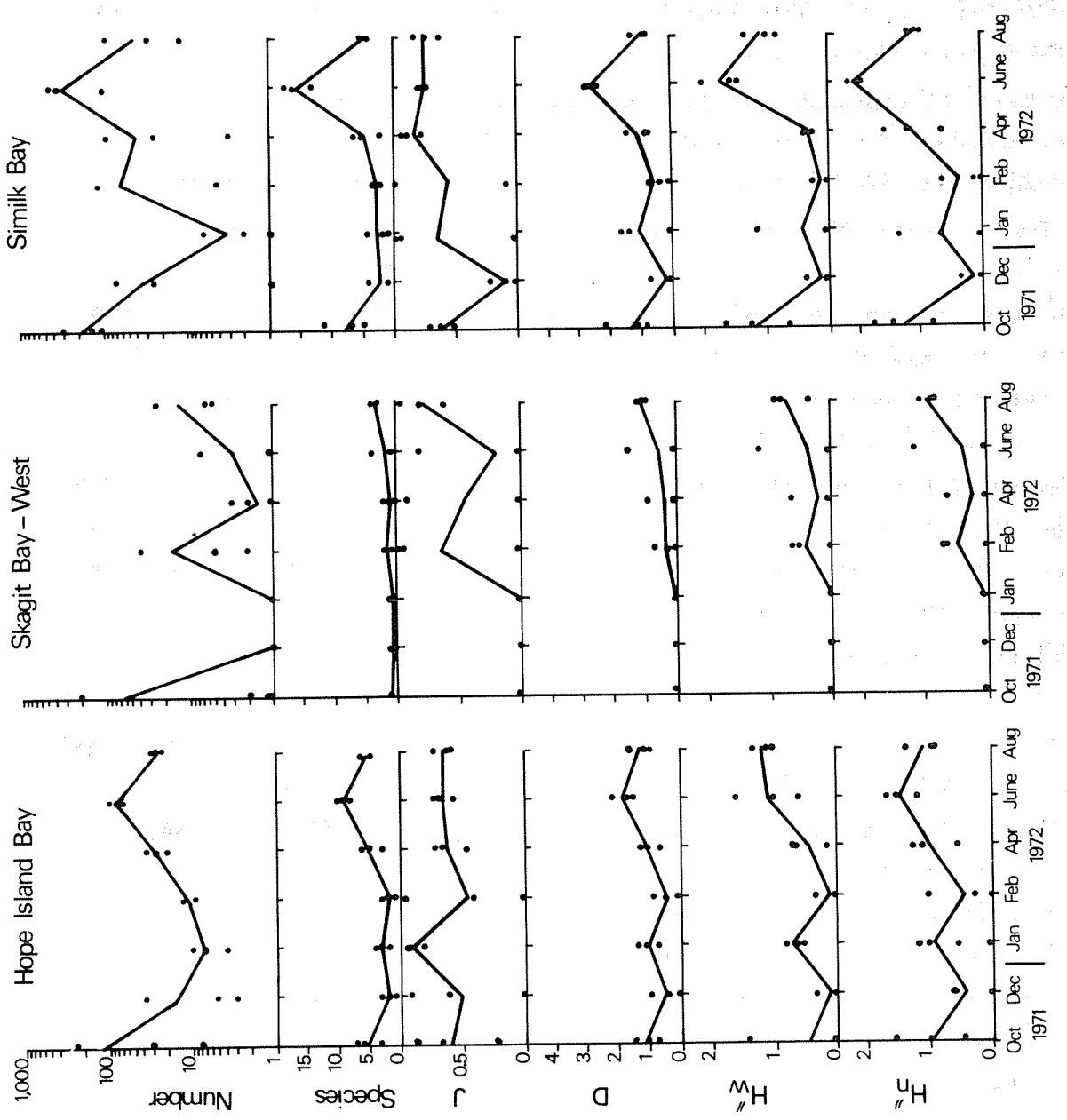

Fig. 9-4. Bimonthly calculated diversity indices of H", H''_w, J, and d compared with numbers of species and sample sizes sampled by beach seine.

August whereas the highest values for H, d, and J occurred in April and May. The seeming contradiction may be explained by the fact that the number of species present in Dahlberg and Odum's (1970) study area did not change appreciably, but that sample size was low in April and May; thus sample diversity was greater. Such a situation was not observed in this study because the number of species had a large range, suggesting that there are differences in biological systems that will have to be considered if comparisons of diversity trends are attempted.

9.3.6 Midwater Trawl Catch

Shown in Fig. 9-5 are the calculated diversities, H''_n, H''_w, J, d, the number of species, and the number of individuals, for the catches by midwater trawl. Although there were large variations between the samples from the different depths for a given area with H''_n, H''_w, and J, they were not statistically significant.

Analysis of variance indicated that the number of species captured was significantly different (.05) when compared by months, Table 9-2. June samples had significantly lower numbers of species. All other parameters were nonsignificant when analyzed by station and month.

Diversity indices for the samples taken by midwater trawl displayed patterns that could not be related to those taken by the other gear nor to the observed environmental changes in salinity and temperature. The number of species captured was significantly lower (.01) during June 1972 and this scarcity cannot be explained. It is certain that midwater sampling would have to be more frequent and several replicates would be required at each depth; however, describing a water column in terms of species diversity is at best tenuous because pelagic fish generally undertake extensive seasonal and diurnal movements and tend to school, producing a nonuniform distribution within the water column.

9.4 SUMMARY AND CONCLUSIONS

1) The resident marine fish community in the three bay areas surrounding Kiket Island was sampled bimonthly from August 1970 to August 1972 with four types of gear (i.e., otter trawl, trynet, beach seine, and midwater trawl).

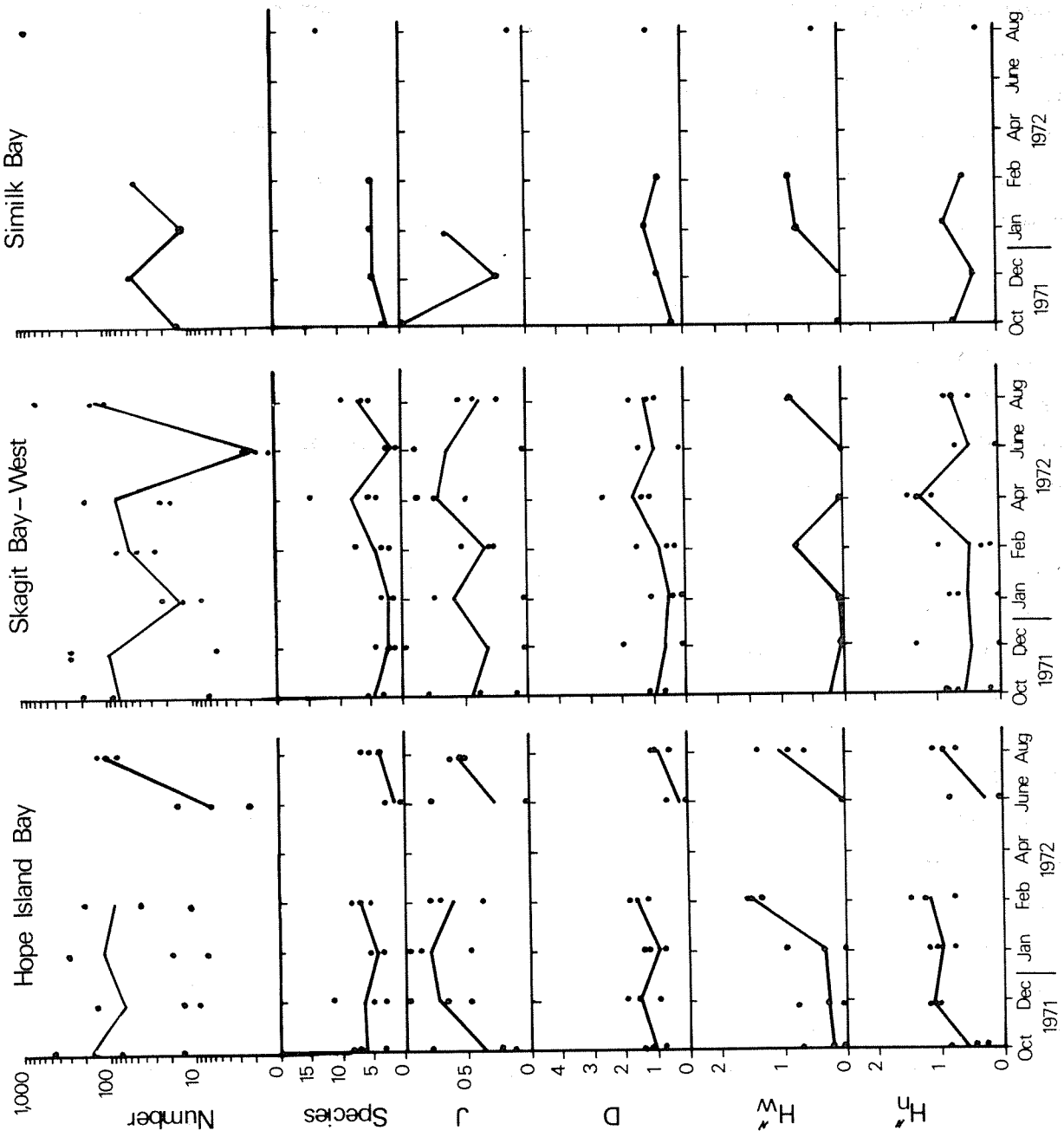

Fig. 9-5. Bimonthly calculated diversity indices of H''_n, H''_w, J, and d compared with numbers of species and sample sizes sampled by midwater trawl.

The sample diversities for each area were different because habitats sampled varied with depth from in- to offshore; environmental conditions changed with seasonal temperature and discharge from the Skagit River; life cycle requirements and tolerance to change differed among the most abundant species in the community.

2) A total 68,725 fish were captured comprising 86 species, and 1 hybrid in 28 families. The percentage of the total catch by otter trawl, trynet, beach seine, and midwater trawls were 88.9, 2.2, 4.4, and 4.5 per cent, respectively.

3) Eighty-nine per cent of the total catch ranked by number of individuals consisted of 14 species in 10 families. In decreasing order of abundance they were: Pacific tomcod, shiner seaperch, English sole, Pacific herring, spiny dogfish, longfin smelt, pile seaperch, staghorn sculpin, butter sole, rock sole, surf smelt, snake prickleback, shortfin eelpout and bigfin eelpout.

4) Ranked by biomass, 89.1 per cent of the catch was composed of 9 species in six families. In decreasing order they were: spiny dogfish, Pacific tomcod, English sole, big skate, rock sole, shiner seaperch, butter sole, copper rockfish, and pile perch.

5) Species diversity indices calculated were: the Shannon-Wiener (H''_n and H''_w), species richness index (d), and the evenness (J).

6) Statistical comparisons of the diversity indices calculated for the three otter trawl sampling stations indicated a significantly larger species richness (d) in the area designated Skagit Bay-West, while in Hope Island Bay the number of species was reduced; however, the number of individuals was more evenly distributed. Similk Bay had the lowest diversity with fewer species and large numbers of individuals. Pacific tomcod and shiner seaperch juveniles were most abundant during August and October. Seasonal changes in diversity were not significant due to the negligible effect of the Skagit River on the water quality in the deep water sampling areas in Skagit Bay-West and Hope Island Bay; however, this was not the case in Similk Bay.

7) Shallow areas sampled by trynet and beach seine were most affected by changes in water quality due to seasonal changes in temperature and salinity as a result of runoff from the Skagit River. Significantly lower diversities and associated numbers of species and specimens occurred during January - April of both years.

8) A large diverse community of fish exist in North Skagit Bay. Future changes either natural or man caused can be assessed against this baseline data. The placement of intake or discharge structures near Kiket Island must consider the potential entrainment effects on the juvenile members of this community.

10.0 ONSITE EXPERIMENTAL THERMAL EFFECTS STUDIES

10.1 EFFECTS OF TEMPERATURE ON RATES OF OXYGEN UPTAKE BY SUBTIDAL BOTTOM SEDIMENTS

by

D. L. Mayer

10.1.1 Introduction

Studies of aquatic community metabolism have become widespread since Odum (1957) studied community trophic structure and productivity in a Florida freshwater spring. The majority of the studies have relied on the rate of oxygen uptake as an index of community metabolism. Oxygen consumption by sediments has been shown to be a function of organic and inorganic chemical oxidation by Moore (1931) and ZoBell and Anderson (1936). This separation between the rates of respiratory and inorganic oxidation has been demonstrated in sediments from Puget Sound by Pamatmat (1971). No more than 17 per cent of the benthic respiration could be attributed to the macrofauna, according to Carey (1969) this finding is in close agreement with that of Wieser and Kanwisher (1961), who divided the respiration among the components of an intertidal mud community as follows: nematodes, 10-33 per cent; macrofauna, 10-15 per cent; and bacteria and protozoa, over 50 per cent. Pamatmat (1969) found no significant correlation between the ash-free dry weight of macrofauna and the oxygen consumption of bottom cores. His conclusion was apparently based on macrofauna densities found in grab samples collected in the experimental areas and the respective macrofauna densities of the cores used in measurements of oxygen uptake. Any relationship between macrofauna densities and oxygen consumption could be masked by the larger uptake of macrofauna and inorganic oxidation of the sediments. Normal sampling variance among benthic samples would require a large sample size of grab samples and measurements of oxygen uptake in independent core samples to detect a correlation between uptake of O_2 and macrofaunal abundance. Rates of oxygen uptake in Puget Sound sediments have been measured and discussed by Pamatmat and Banse (1969) and Pamatmat (1971).

Rates of oxygen uptake by sediment cores have been reported in studies by Hayes and MacAulay (1959), Teal and Kanwisher (1961), Edwards and Rolley (1965), Carey (1967), and Pamatmat (1971). These studies were conducted in closed systems and the results were based on oxygen depletion from the water overlying sealed core samples. The closed system produced an artificial stress on sediment biota and biased results. The rate of sediment oxygen consumption was related to the oxygen concentration of the overlying water in studies by Hargrave and others (Hargrave, 1969). Rates of consumption were severely reduced below oxygen concentrations of 6.0 ml O_2 l^{-1}. In Carey's (1967) sediment core samples the rate of oxygen uptake was directly proportional to the stirring rate up to the point of sediment erosion.

The metabolism of the bottom sediments as measured by a bell-jar closed system was compared with that in a continuous-flow apparatus by Pamatmat (1965). His findings indicated that flows from 0-50 cm/min had no significant effect on short-term measurements of metabolism but that peak periods of respiration occurred during periods of peak current velocities. He cites similar findings by Fox, Simmonds, and Washbourn (1935) that metabolic rates of sediments were positively correlated with current velocities. Pamatmat (1965) concluded that the reliability of bell-jar techniques is greater than Odum and Hoskin (1958) felt it might be.

In core samples the volume of water overlying the community is much smaller, however, and O_2 levels become depleted more rapidly. CO_2 concentrations would also increase more rapidly than in a bell-jar environment. These findings, in addition to the known acceleratory effect of increased CO_2 concentration on the ventilation rates of many marine invertebrates (Nicol, 1960; Prosser and Brown, 1960), suggested that a constant-flow respirometer would be an improvement in technique. In addition, since the question of temperature increases due to thermal discharge concerned short-term changes, it seemed desirable to treat the cores with warmed surface water and maintain the subsurface sediments at near-ambient temperatures at the same time.

10.1.2 Materials and Methods

The following study was designed to show the response of the benthic community to increases in water temperature as a function of oxygen uptake in core samples. Initially it was planned to develop a community energetics model from which the effect of a thermal increase on the energy flow and balance in the benthic community could be predicted. As the studies progressed, it became apparent that the problem contained many unresearched aspects. Detailed knowledge of the community composition, structure, and functional dynamics was lacking. Emphasis in the research was shifted to these deficient areas, and at the same time the studies of oxygen uptake by the sediments were continued for procurement of collaborative evidence for the lethal thermal tolerance studies of benthic infauna.

A continuous-flow respirometer was designed and constructed to operate in connection with the laboratory's running sea water system. Core samples containing 10 cm of sediment and 9 cm of water were collected by hand by the use of SCUBA from a depth of 20 ft in the region of the underwater pen experiments (Fig. 8.2-1). The samples were collected in 24/40 Kimax ground glass female fittings measuring 20 cm x 2.35 cm in diameter. Male portions of the joints were modified with inlet-outlet stems connected in series with Tygon plastic tubing to the probe manifold (Fig. 10-1). As each core sample was collected, the sample was secured at both ends with rubber stoppers. A two-holed stopper was used in the upper end in order to allow continuous water exchange between the core sample and ambient water. Cores were transferred to the laboratory within 30 min. On shore the cores were placed immediately in ambient running sea water and held approximately an hour before use.

The core respirometer, Fig. 10-1, was designed to operate in conjunction with the Model 54 oxygen meter (Yellow Springs Instrument Company). The sensing element was a polarographic electrode which when polarized at 0.8 v produces a current that is directly proportional to the partial pressure of oxygen. The instrument was temperature compensated to read directly in ppm of O_2 with an accuracy of ± 1 per cent at full scale (0-10 ppm). Standard and high sensitivity teflon membranes were tried. The high-sensitivity membrane was discarded in favor of the standard membrane since the latter seemed less susceptible to fouling by unfiltered sea water. Water samples were collected

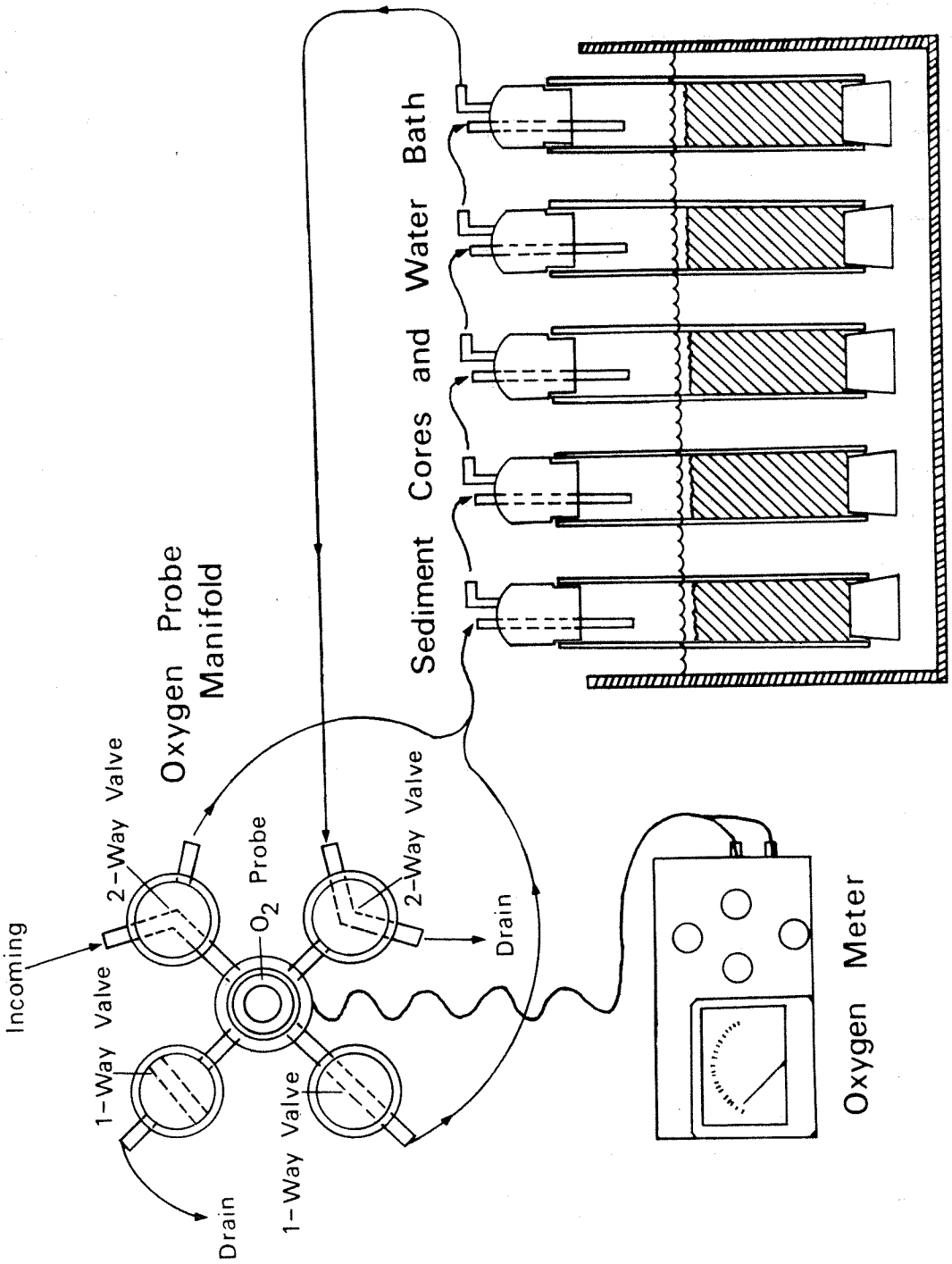

Fig. 10-1. Schematic representation of benthic core respirometer apparatus used to measure oxygen consumption rates versus water temperatures.

at the beginning and end of each trial. The O_2 concentrations were determined stoichemetrically. The results were used in the final calculations in calibrating the instrument during each trial. This continuous calibration was necessary because of the changes in sensitivity of the probe membrane and in water temperatures.

The initial respirometer had two probes, one on the inflow line and one on the outflow line. Tests showed, however, that the differences in response characteristics of the two probes made comparison of low-level oxygen differences very unreliable. Because of the lack of between-probe comparability, a new system was designed based on a single probe to measure both inflow and outflow O_2 concentrations. The probe was fitted to a glass manifold shown in Fig. 10-1. A system of Teflon valves attached to the manifold permitted the diversion of either inflow or outflow water across the probe membrane. The probe was coupled to the glass manifold by a short section of Tygon tubing attached to the glass manifold with a silicone rubber compound. The probe was held in the Tygon coupling by a standard hose clamp.

Two closed-system laboratory water lines, one for ambient and the other for heated sea water, were adapted to the manifold Tygon tubing. These lines were positioned close to the manifold apparatus and could be quickly removed or attached. The temperature of the heated water was set approximately an hour before each run and allowed to stabilize at a flow rate as close to 6 ml/sec as possible. Flow in the ambient line was adjusted to equal the established flow rate in the heated waterline prior to each experiment.

At the beginning of each trial the intake-output manifold was connected to the top of each of the five cores. The manifold was first connected to the line for ambient sea water. The difference in oxygen concentrations between the input and output ambient water was measured every 2 min. After these observations, the procedure was repeated on the same cores with heated water. Dye introduced into the apparatus indicated a complete turnover in the system in approximately 40 sec at a flow rate of 6 ml/sec. An additional 20 sec was provided for the probe to stabilize; thus an observation of either inflow or outflow O_2 concentration was made every minute. The trial was ended by measurement of the O_2 uptake of the empty system for correction of respiration of organisms and chemicals in the water and attached to the walls of the respirometer.

The cores were submerged to the level of the mud-water interface in a flowing ambient water bath. Black plastic curtains surrounded the apparatus to prevent photosynthesis in the sediments or water. Temperatures in the lower range were determined by ambient water conditions used at the time of the experiments. Elevated temperatures were arbitrarily chosen with reasonable continuity within the range. On occasion, difficulties in adjusting and maintaining hot water production dictated the exact test temperature.

Benthic core samples were also tested for lethal temperature tolerance. Ten core samples, 5 test and 5 control samples, were collected from a depth of 7-9 m in the location of the respirometer sample collections. The cores were collected in the same manner as described for the respirometer experiments. The cores were connected in series in sets of 5 each. One series was connected to a hot sea water line at the particular test temperature. The other series of 5 cores was connected to the laboratory ambient sea water line. Flow rates were set as close as possible to those used in the respirometer experiments.

Treatment temperatures selected were 31, 29, 27, 25, and 23 C. The exposure time was varied to fit the expected mortality rate at the particular test temperature. One core from the treatment group and one core from the control group were removed at the preset time intervals until all five cores in each series had been examined. The cores removed were replaced by a blank core so that the flow rate and circulation patterns would be maintained. Each test temperature was replicated once. During the second replicate, the cores were removed from the line series in the reverse order in which they had been removed during the first trial. This prodecure was followed so that any effect on the results due to the samples' position in the series would be removed.

Upon removal from the line, each core was gently sieved through a 0.495-mm-mesh screen. Ambient sea water was used to rinse away the sample sediment. The organisms retained by the sieve were quickly transferred to a petri dish of ambient sea water and examined beneath a dissecting microscope. Each organism was observed for signs of life on the basis of movement. The number of living and dead organisms were recorded for each species. The samples were then scored for the per cent mortality among the invertebrates examined.

10.1.3 Results

Six experiments involving five replicate cores connected in series were conducted during January 1972. Eighteen experiments of five replicate cores each were conducted in August 1972. As in the studies previously cited, the results of these experiments clearly demonstrated the relationship between water temperature and the rate of sediment oxygen consumption. The mean ambient summer consumption rate was 12.43 ml O_2 hr^{-1} m^{-2} with a range of 6.86 to 20.32 ml O_2 hr^{-1} m^{-2}. The mean ambient winter consumption rate was 6.79 ml O_2 hr^{-1} m^{-2} with a range of 3.62 to 9.51 ml O_2 hr^{-1} m^{-2}.

The results of simple linear regression analysis of findings in both the summer and winter tests are illustrated in Fig. 10-2. Both regression lines explained a significant amount of the variance at the 99-per cent confidence level. The correlation coefficients between rate of O_2 uptake and water temperature for summer and winter experiments were $r = 0.824$ and $r = 0.988$, respectively. The difference between summer Q_{10} (1.51) and winter Q_{10} (1.62) was found not significant in a student "t" test. The difference between the mean rates of O_2 uptake during the summer and winter was significant at the 99-per cent level. Both the Q_{10} (or slopes) of the summer and winter tests were significantly different at the 99-per cent confidence level from those found by Pamatmat (1971) and Hargrave (1969) in similar studies.

When the rates of O_2 uptake were plotted on a linear scale against temperature (Fig. 10-3), the rates showed a steady increase up to temperatures around 23 C. Consumption accelerated with increases in temperature beyond 23 C until 28-29 C and declined at this temperature.

The results of lethal temperature tolerance tests on core samples on benthic invertebrates are shown in Fig. 10-4. A marked increase in mortality occurred between 25 and 27 C, corresponding to the upward shift in the respiration curve shown in Fig. 10-3. Temperatures of 25-26 C represent the region of incipient lethal temperature. Increased respiration due to metabolic stress was followed by a drop in O_2 uptake as thermal mortality began to occur among the macrofauna in the core sample. At temperatures above 27 C the TL_m decreased rapidly. This decline apparently would account for the decline in the respiration curve at these same temperatures.

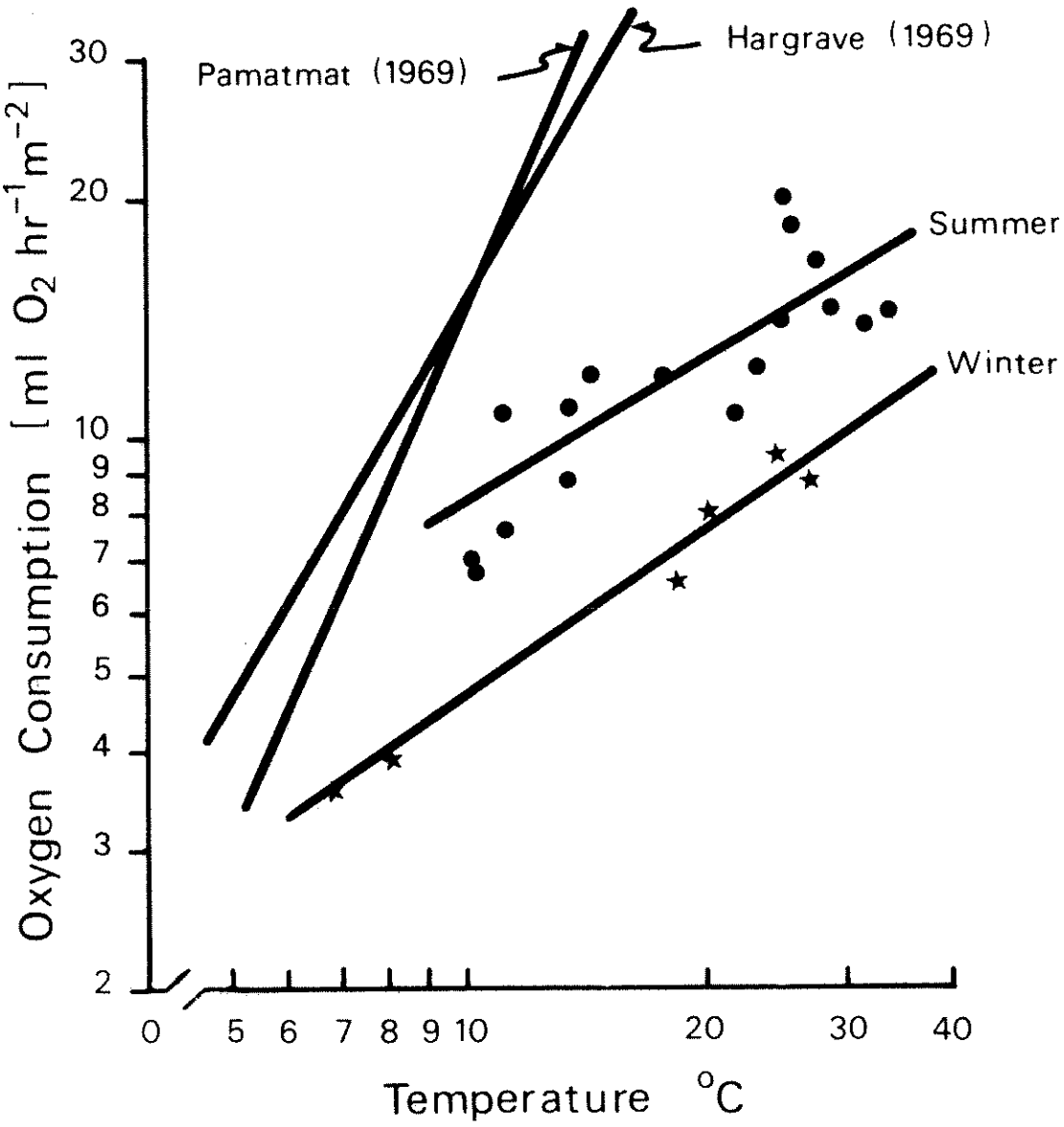

Fig. 10-2. Linear regression of sediment oxygen consumption vs. water temperature. Data points are based on oxygen uptake of 5 cores connected in series. Included are the linear solutions to equations reported by Pamatmat (1969) for Puget Sound and Hargrave (1969) for a variety of uptake studies.

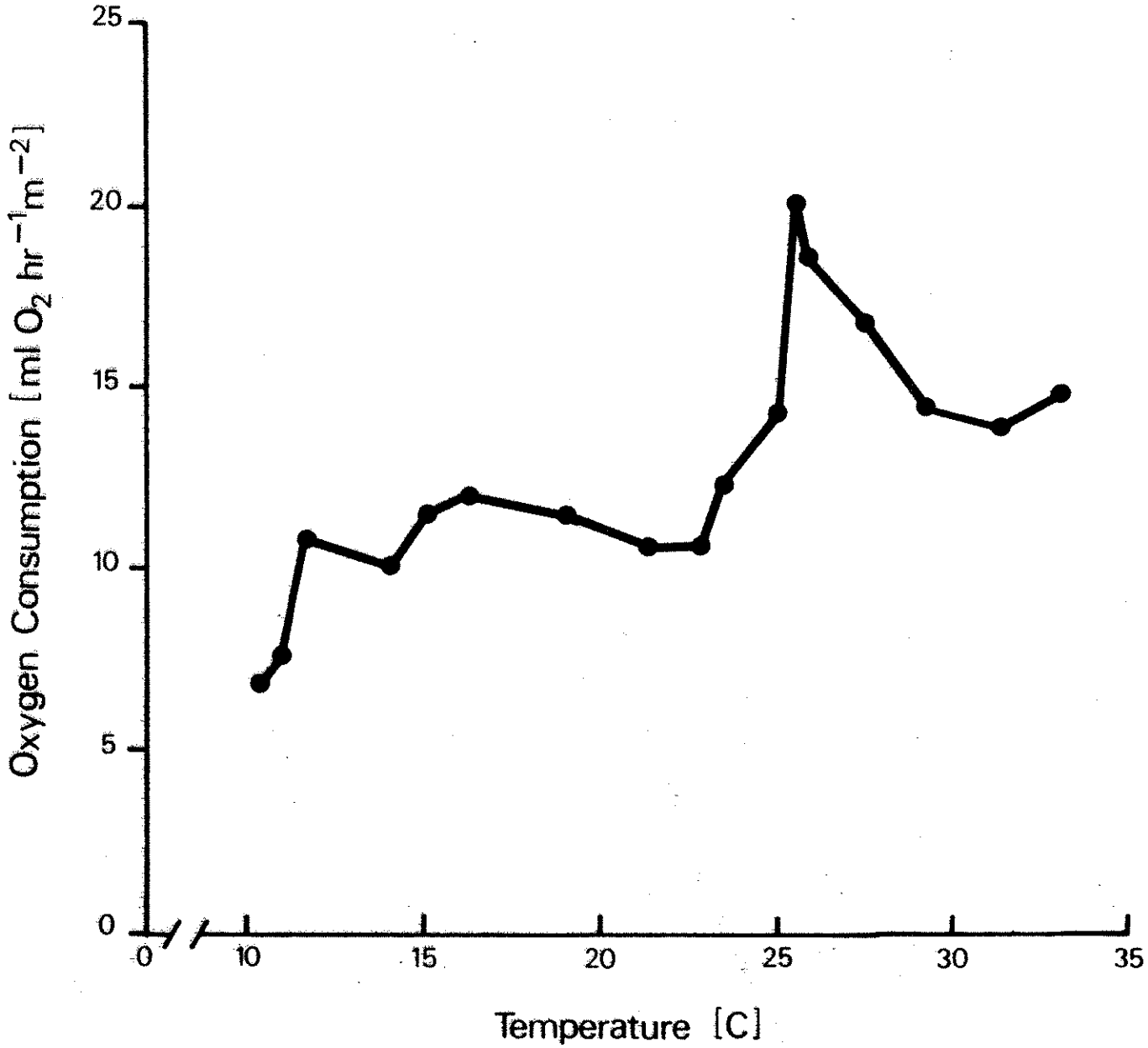

Fig. 10-3. A plot of oxygen consumption rate measured in the respirometer versus water temperatures. Data points are based on the oxygen consumption rate of five cores connected in series.

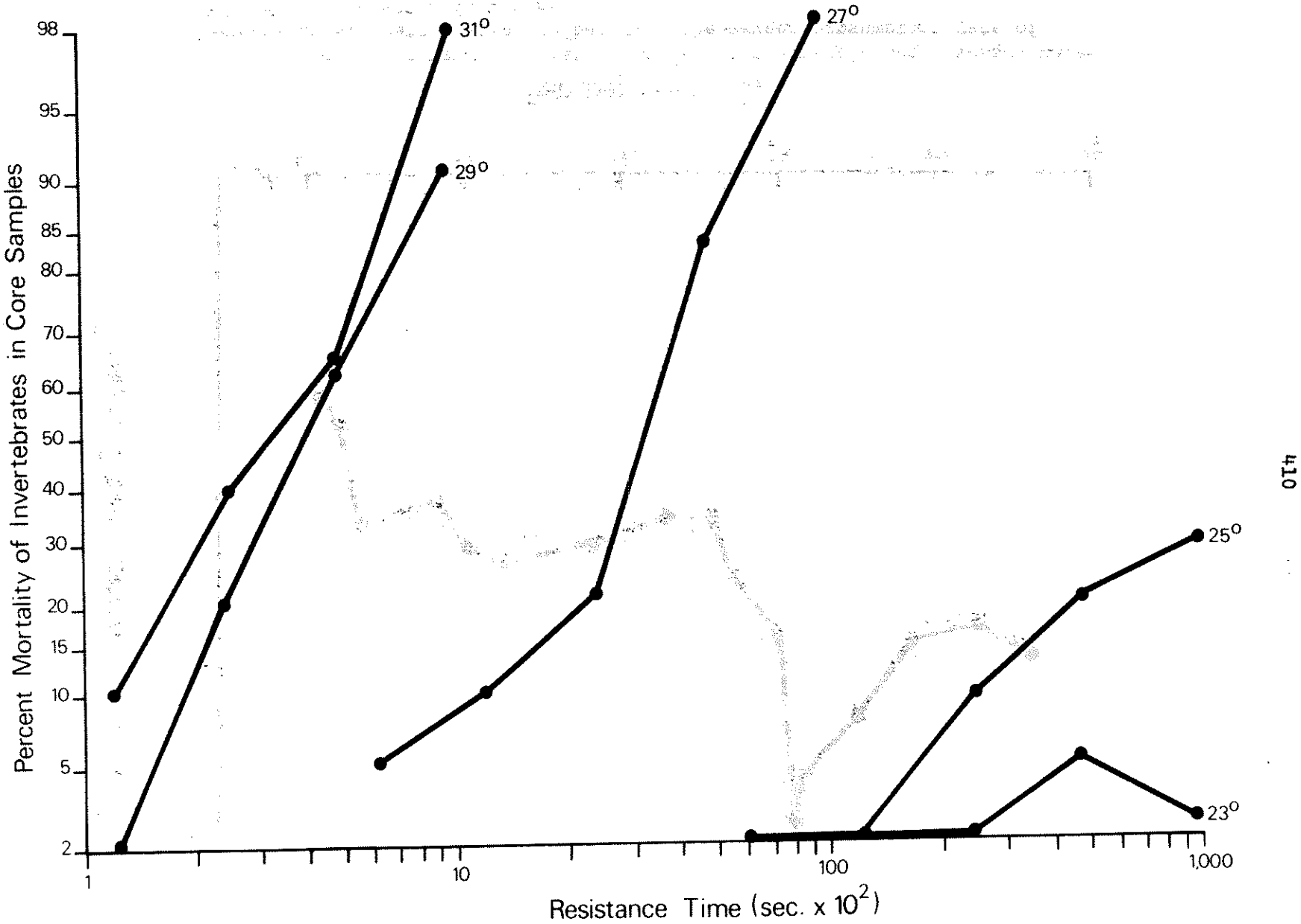

Fig. 10-4. The resistance time in seconds of meiofauna (<0.5mm) at 23, 25, 27, and 31 C. Each data point represents the mean of two independent replicate trials.

Because of the variable occurrence of particular species among the random core samples, only qualitative comparisons of the thermal sensitivity between species were possible. Inspection of the resulting data showed that the crustaceans, particularly the photid amphipods, were the least tolerant of elevated temperatures. The amphipods were followed in decreasing sensitivity by the clams, *Transenella* and *Nucula*, and the polychaetes, *Terebellides*, and *Praxiella*. The maldanid polychaetes appeared to be the most tolerant of the invertebrate species examined.

10.1.4 Discussion

The dissimilarity between the Q_{10} found in this study and those reported in other similar studies of sediment oxygen consumption are illustrated graphically in Fig. 10-2. The two most likely explanations for these results involve differences in experimental methodology.

As pointed out in the introduction, a continuous-flow system such as that used in the present study, may provide a less stressful environment than a closed system for infauna by exchanging oxygen, carbon dioxide, and metabolic wastes. Thus rates of ventilation would be lower and consequently rates of oxygen consumption would be less. The contribution of stagnant conditions to rate of oxygen consumption appears to be in doubt in the literature. Circulation and current speed apparently increase O_2 uptake (Carey, 1969; Pamatmat, 1969; and Hargrave, 1969). However, physiological studies of individual species of marine invertebrates Prosser and Brown (1960) would suggest acceleration of rate of ventilation and rate of oxygen uptake with declining O_2 concentrations to a point of physiological failure. The role of circulation in the present study is undetermined.

In the present study the sediment portion of the core was cooled by an ambient water bath. This cooling effect would restrict increases in temperature, within the sediment to the mud-water interface and a small fraction of sediment immediately below the surface. In contrast, the methods used in the other studies in which the core samples were heated over their entirety would effectively increase the rate of O_2 uptake by increasing the amount of biological activity affected by the temperature increase. It is felt that this difference in methodology is the largest single factor contributing to the difference between results.

Although a trend was seen between the numbers of macrofauna retained on a 0.495-mm-mesh screen and the rate of O_2 uptake, no significant correlation was encountered. This finding is primarily due to the small contribution of the macrofauna respiration to the benthic community's total oxygen consumption.

The pattern of changes in rate of uptake seen in Fig. 10-3 agrees with the respiratory responses of many marine invertebrates as discussed by Newell (1971). Metabolic rates are adapted to accommodate normal environmental ranges. Beyond this range physiological stress causes acceleration of the Q_{10} with increasing temperatures. Further temperature increase eventually causes physiological collapse and death of the organisms. The drop in respiratory rate in the region of 28-30 C corresponds to the region of observed mortality in heat-treated cores. The shift in Q_{10} in the 23-25 C region may represent the area where sublethal temperature effects exceeded the organisms' capacity for physiological accommodation.

10.2 THERMAL TOLERANCE OF *CANCER MAGISTER* EGGS

by

D. L. Mayer

10.2.1 Introduction

Egg deposition by the female Dungeness crab is accomplished up to 4 months after mating and fertilization by the male crab. Mating generally occurs in late spring and throughout the summer. The female retains the sperm packet internally until late fall or winter. Each egg is fertilized as it passes through the oviduct before attachment to the hairs on the female's pleopods beneath her telson. The eggs accumulate as a large mass beneath the telson. They may be carried this way for up to 3 months. As the eggs ripen, the embryonic larvae pass through several larval stages inside the eggs. Finally, they hatch in the early spring as zoea.

Literature on the reproductive biology of the Dungeness crab is very scanty. It consists mostly of chance field observations and limited laboratory studies. The life cycle of and reproductive timing in the market crabs

were first described by McKay (1942). He feels that mating takes place primarily during the warming months of May and June, although mating or clasping activity may occur throughout the year. Detailed observations of the mating behavior under laboratory conditions were made by Snow and Neilsen (1966). No information exists, however, on the role played by environmental factors in the fertilization, maturation, or hatching success of Dungeness eggs. From his studies in progress of the Dungeness crab's temperature sensitivity, Des Voignes (personal communication) has noted a strong effect of photoperiod on mating behavior. His studies include some considerations of the effect of temperature on reproductive success, i.e., egg production, per cent fertilization, etc. The present study was an attempt to develop information on the thermal tolerance of *Cancer magister* eggs. This information will be combined with the results of two studies: the study of the thermal tolerance of the larva by Reed (1969) and the earlier phase of this study on the resident adult. Together these studies will show the crab's thermal sensitivity over its life span. No information was developed for the juvenile and sublegal adults as they are unavailable in the study area.

10.2.2 Materials and Methods

Samples of eggs were collected from ovigerous and berried females. "Berried" females were taken from November to July, as seen in Fig. 10-5. The locations of the sampling stations listed in Fig. 10-5 are illustrated in Fig. 8.2-3. During the winter months of 1971, a number of females were collected, taken to the laboratory, and stripped of their eggs. An attempt was made to collect individuals with a representative range of sizes. The eggs were stripped with a dull butter knife. The stripped females were measured to the nearest tenth of a centimeter, marked with a Floy anchor tag, and released in front of the laboratory. The volume of eggs from each female was measured to the nearest tenth of a milliliter by total volume and volumetric displacement. Precise volumetric subsamples were collected and counted under the microscope.

Testing was conducted aboard the R.V. *Kumtuks* at the University of Washington. On March 4, several samples of eggs were collected at Kiket

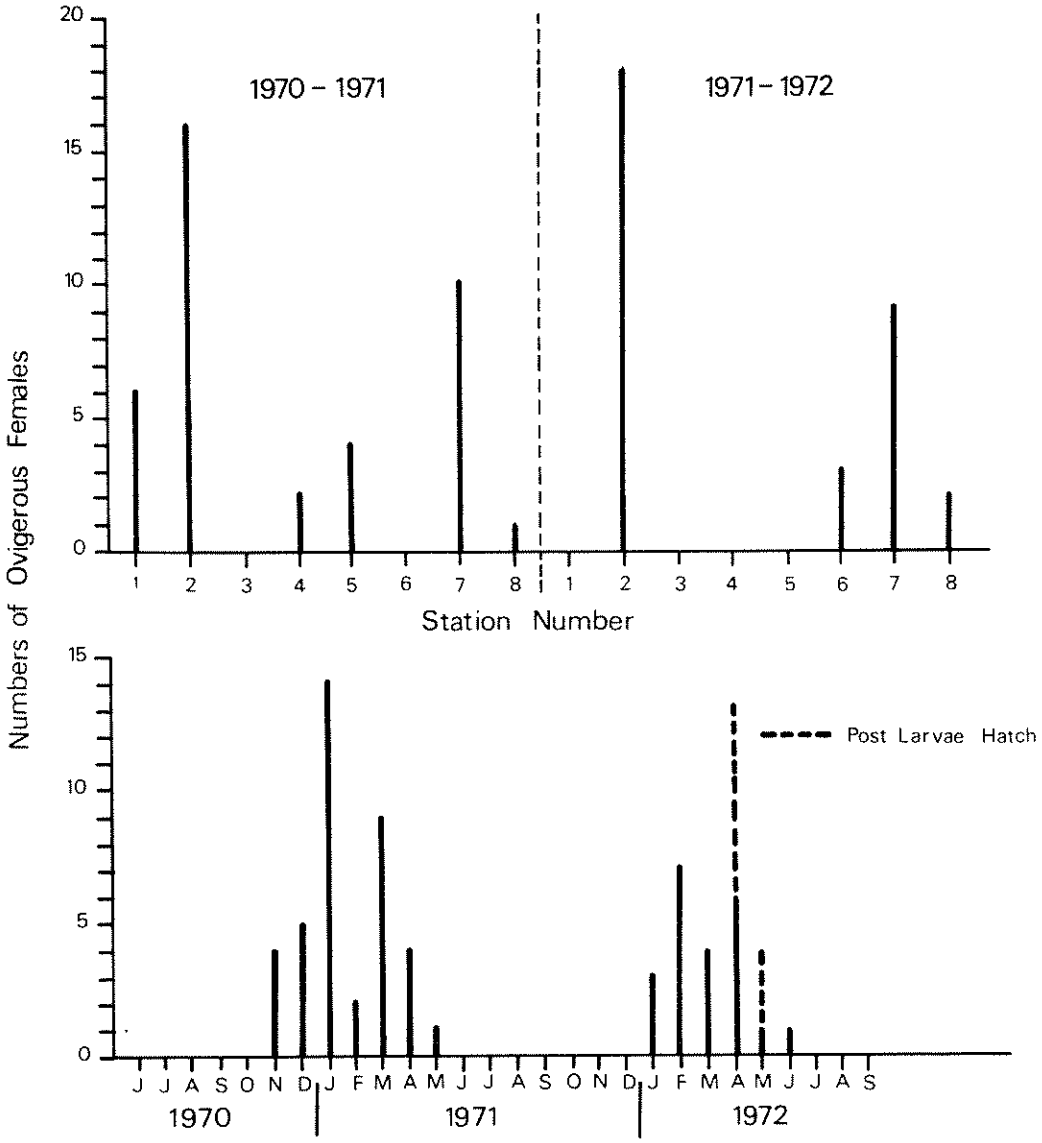

Fig. 10-5. The number of ovigerous female, *Cancer magister*, collected in the study crab pots during the period of July, 1970 to September, 1972. Catches are plotted by month for all stations. Included are the catches for each station.

Island and brought to the R.V. *Kumtuks* at the University of Washington. Ambient sea water carried from Kiket was filtered three times through micropore filters. In accordance with Poole's (1966) procedure, the sea water was treated with 250,000 units of penicillin and 2,500 mg of streptomycin. Nearly equal amounts of egg clusters, 1 ml, were attached to 5-inch glass stirring rods with rubber bands. The rods were placed in a leaning position in 250-ml wide-mouth glass jars such that the eggs were freely suspended in the treated water. The 200 ml of treated water was changed approximately every 3 days. The egg samples were held at four test temperatures. Eggs were held at 5 C and 10 C in refrigerators and at 15 C and 20 C in thermostatically controlled water baths. Two experimental groups of eggs from different sampling dates were tested. Two replicates per experimental group were exposed to each treatment temperature.

Before the eggs were exposed to treatment they were determined to be 100 per cent viable by microscopic examination. Viability was determined from the presence or absence of embryonic activity. Immediately prior to the change of water every three or four days, a subsample of 100 eggs from each treatment sample was examined under the microscope for mortalities. Mortality was determined also from the presence or absence of activity in the egg capsules.

10.2.3 Results

The counts of eggs in a 1-ml subsample ranged from 15,211 to 17,692 with a mean of 16,923. Based on the observed mean egg diameter, it was also calculated that 1 ml of eggs would contain 15,611 eggs. Estimates from both methods of determination agreed reasonably well.

The measured total volume of the egg mass of the 25 females sampled were converted to total number of eggs by use of the value of 16,000 eggs/1 ml. A significant amount of variance between width of carapace of the female and the number of eggs deposited was explained by the linear equation $Y = -2.45 + 0.29\ X$, relating total eggs, Y, deposited X 10^6 to width of carapace, in centimeters. This relationship is shown graphically in Fig. 10-6.

The results of the first experiment on egg mortality, which began on March 4, agreed closely with the results from the following replicate experiment, which began on March 24. A factorial analysis of variance showed no

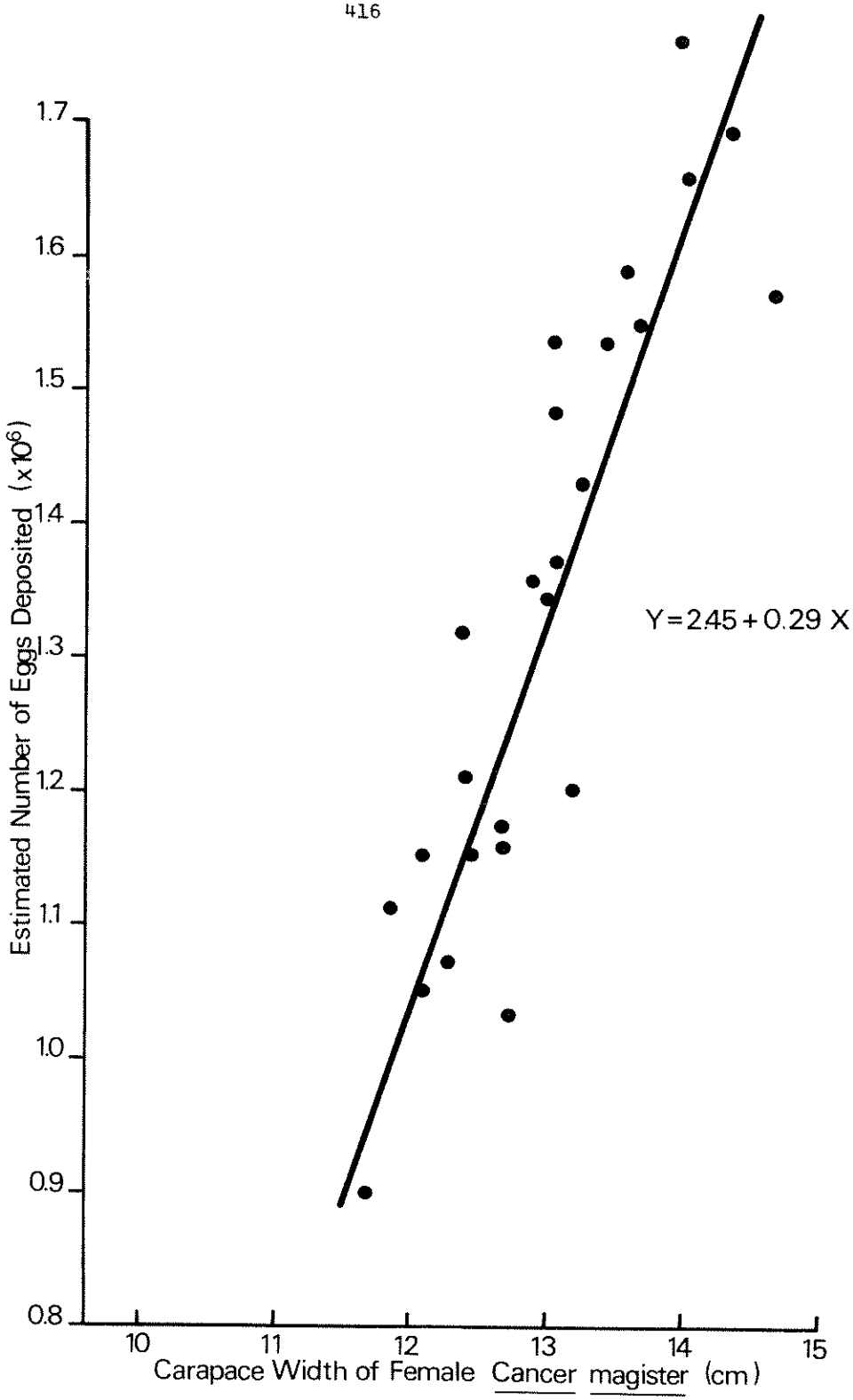

Fig. 10-6. Linear regression of the relationship between the number of eggs deposited among a sample of ovigerous females and their width. Widths were measured across the widest point of the carapace exluding the most posterior lateral teeth.

significant difference between replicates at a given temperature dose nor any significant difference between experiments. The results of the treatments at 5, 10, 15, and 20 C differed significantly at the 99 per cent confidence level.

The percentage of egg mortality as a function of the natural log of exposure time in minutes is shown graphically in Fig. 10-7. Treatments at 5 and 10 C produced only slight effects. The mortality among the eggs at 5 C represents both the natural mortality and the mortality due to experimental method. At 10 C mortality increased. Significant increases in mortality were observed in eggs held in 15 and 20 C water.

Increased bacterial growth was noticeable at the 10th day in both the 15 and 20 C treatments. A layer of foggy material covered the eggs. Water changes seemed to do little to improve the condition. Bacterial growth was not observed in the 5 and 10 C treatments. Microscopic examination of the eggs at each of the sampling-time dose intervals also indicated increased bacterial and protozoan activity in the 15 and 20 C treatment groups. There were larger numbers of Hypotricha at these temperatures. All egg masses held a wide variety of commensual animals. Gross observations seemed to indicate that changes were occurring in the number and composition of these animals.

10.2.4 Discussion

As mentioned in the introduction, no similar information on the temperature tolerance of Dungeness crab eggs was found in the literature. Fecundity was briefly estimated by McKay (1940) at between 1 and 2 million eggs per female. Poole (1966) makes brief mention of egg-handling methods. Both Poole (1966), Mir (1961), and Reed (1969) discuss their observations of larval mortality. Poole (1966) refers to observations of increased protozoan and bacterial growth before the introduction of antibiotics.

Results from the present study demonstrate a significant increase in embryonic mortality at temperatures as low as 15 C. Interpolation between the mortality curve at 10 and 15 C would suggest an incipient lethal temperature of approximately 12 C. Increased mortality at 10 C may represent a synergistic effect between experimental conditions and elevated temperatures. While this effect would apply to all treatments, the results at 15 C indicate a

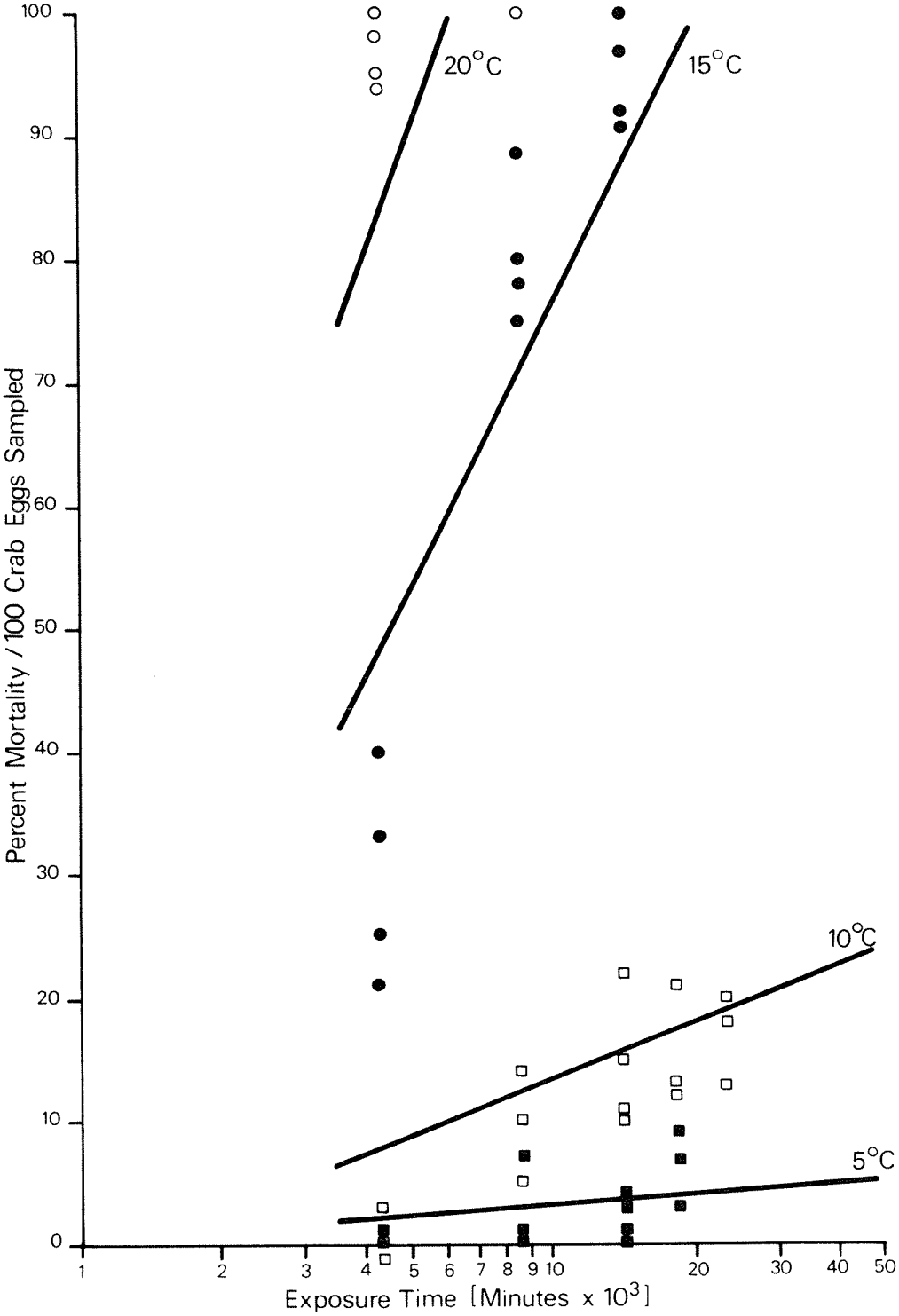

Fig. 10-7. Hand fitted lines expressing the relationship between per cent mortality in *Cancer magister* eggs to exposure times in minutes at 5, 10, 15 and 20 C sea water. Salinity was nearly constant at 25°/oo. Each data point represents the results observed in a 100 egg subsample.

significant increase inthe slope of the mortality curve due to the effect of elevated temperatures between 10 and 15 C.

It is possible to estimate the effect of elevated temperatures on an ovigerous female crab's offspring from the average fecundity rate found among the 25 females sampled in the present study and the results from the egg thermal tolerance experiments. Based on the TL_m at 15 C, a 6-day exposure at this temperature would result in a mortality of 1/2 million eggs per female crab. Exposure times at lower temperatures would produce proportionately lower egg mortality rates. Since the eggs are normally carried in round masses, the innermost eggs may be afforded some protection from elevated temperatures.

A "berried" female's avoidance of increased water temperatures might play an important role in preventing egg thermal mortality. No ovigerous females were tested in the thermal gradient experiments. Catches of female crabs were highest during the winter and spring. This increase in occurrence suggests an onshore movement during periods of minimum temperatures. During this period temperatures in the sampling area were rarely above 9 C.

The Dungeness crab is a coldwater species; its southernmost limit is Monterey, California. Several people have examined the relationship between thermal tolerance and survival at different stages of the crab's life history. Woelke (1970) found a statistical relationship between year class strength and water temperatures during the hatching period. Reed (1969) was unable to find, however, any significant larval mortality at temperatures and salinities normally encountered along the Oregon and Washington coasts. As seen in the results of the present study, significant mortalities occur among eggs at temperatures lower than the lethal levels Reed found for larval stages. The eggs' temperature tolerance may be a significant factor in the reproductive success of the Dungeness crab populations.

10.3 RESPONSE OF DUNGENESS CRAB IN A THERMAL GRADIENT

by

D. L. Mayer

10.3.1 Introduction

Knowledge of a species' incipient lethal temperature regime makes it possible to predict the extreme elevated temperatures in a closed system under a given set of environmental conditions. A prediction based on temperature increases in an open system requires additional knowledge of the animal's behavioral response to an increasing thermal gradient. For sessile animals, such as attached or burrowing invertebrates, the possibility of surviving lethal temperature levels through emigration is nearly nonexistent. For mobile animals, such as fish or crabs, emigration away from increasing or lethal temperatures is an important aspect of survival. At sublethal temperatures, avoidance behavior of elevated temperatures may play a significant role in the presence or absence of a species in the normal community.

10.3.2 Materials and Methods

A thermal gradient apparatus was constructed in the onsite laboratory described by Stober (1972). One of the six 1 x 2 x 12.5 ft troughs was modified such that two linear gradients each 1 x 1 x 12 ft were produced. The troughs were of fiberglass-lined plywood of a light green color and had a capacity of 187 gal. During the gradient experiments half this volume of water was maintained in each trough.

The laboratory had a recirculating freshwater supply that was heated with an automatic, oil-fired boiler (Stober, 1972). Sea water was supplied by an offshore submersible pump and passed around the heated freshwater in a shell-and-tube heat exchanger (Corning Model 600GRB). This system was capable of producing 20 gpm of sea water with a maximum temperature increase of 20 C. Ambient water was also supplied to the laboratory by the same pumping system and distributed by a larger header pipe in the wet laboratory. Heated sea water leaving the heat exchanger was mixed with ambient sea water for the

desired temperature in an automatic temperature control valve (Honeywell Model #1601). This control system, when in good working order, was capable of maintaining sea water temperatures within ± 0.1 C. Extreme tidal fluctuations reduced the accuracy to within ± 0.5 C (Stober, 1972).

The thermal gradient was established in the trough through the combination of ambient and heated sea water with constant velocity and nearly constant temperatures. The two were mixed and distributed in a single 1-1/2-inch PVC pipe. As shown in Fig. 10-8, the pipe was cut to the length of the trough and fitted with elbow joints at each end. The ambient water was drawn directly from the overhead 6-inch common head pipe through 1-1/2-inch pipe and regulated with a 1-1/2-inch ball valve. Heated sea water was delivered to the opposite end of the gradient manifold from a 1-1/2-inch header pipe through 3/4-inch Tygon tubing. It was regulated by a 1/2-inch ball joint.

The 12.0-ft 1-1/2-inch PVC gradient manifold pipe was ventilated by a pair of 1/8-inch holes drilled opposite each other at an angle of 60° and spaced 2 inches apart. The pipe was placed 1/2-inch off the bottom in the center of the trough with each pair of holes directed toward the bottom of their respective sides of the trough. Each of the two compartments formed in the division of the trough by the gradient manifold was supplied with an identical number of small water jets of mixed ambient and heated sea water. As the ambient sea water flowed from one end of the manifold to the other, it was mixed with the heated sea water traveling through the manifold in the opposite direction. The mixed water entered the gradient trough through the ventilation holes. Water left the gradient trough by way of a 6-inch standpipe drain located at the warm end of the gradient. A 12.5- x 0.5-ft length of 1-inch-square-mesh vinyl-coated fence was attached to the gradient manifold pipe to separate the trough into two compartments. In this way two crabs could be used in the same experiment (Fig. 10-8).

Incoming velocities of heated and ambient water were adjusted at the header valves until the desired gradient was produced in the trough. Prior to each experiment a period of 1-2 hr was necessary for adjustment of the velocity and stabilization of the heating system and gradient pattern. The average current velocity in the trough was 3.48 cm/sec. This produced a flow rate of 42 cm^3/sec. Introduction of dye into the trough indicated a generally uniform current pattern with small eddies along the sides and above the

CRAB THERMAL GRADIENT APPARATUS

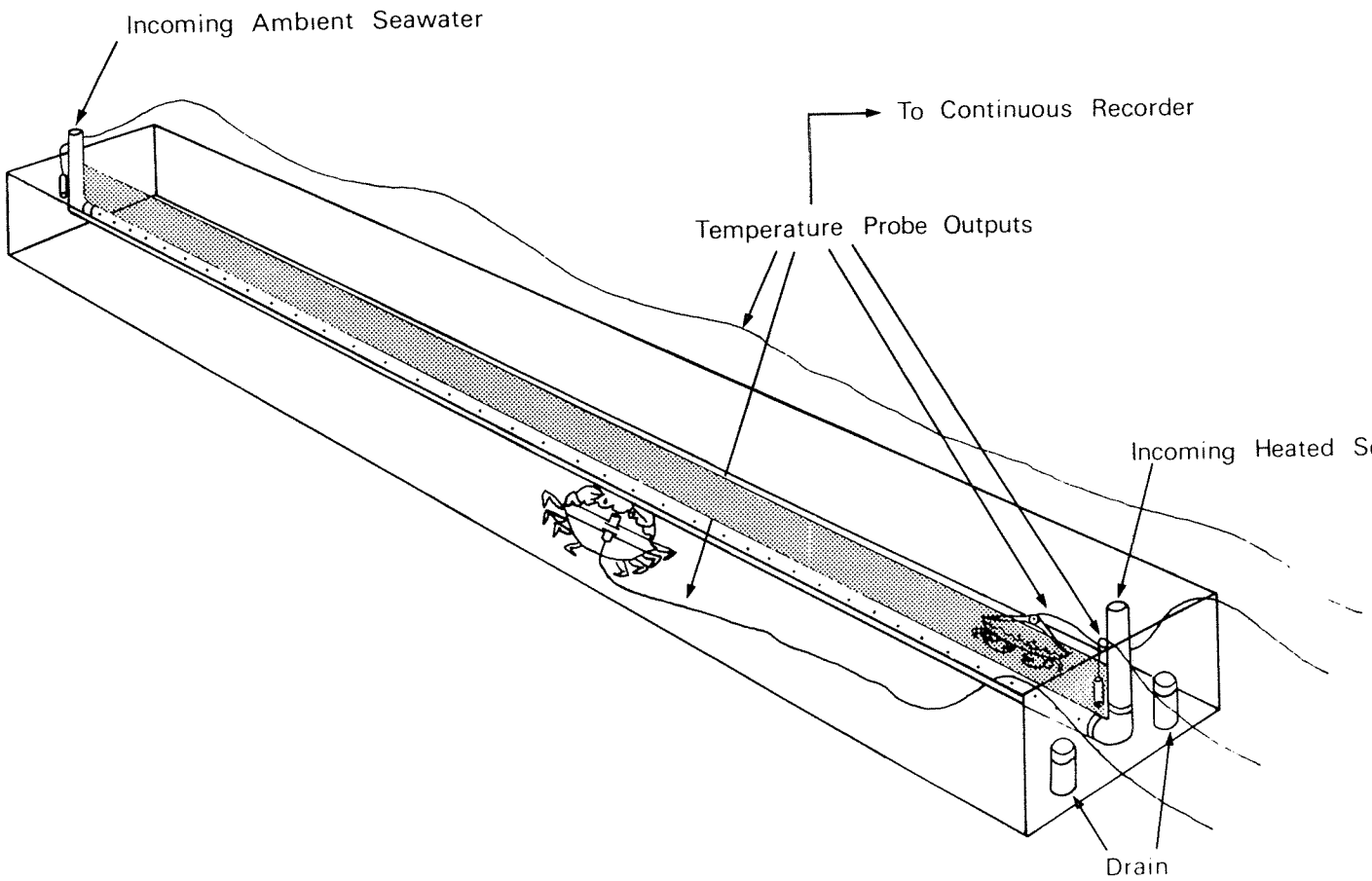

Fig. 10-8. Schematic representation of thermal gradient apparatus used to measure the preferred temperature of *Cancer magister*.

manifold pipe. Current velocities appeared to increase slightly toward the standpipe drain. In order to assess the influence of unequal current velocities, the hot and cold ends of the gradient were reversed during several experiments by altering the drain location. There was no discernible difference in the crab's behavior in the gradient.

The crabs used in the experiment were caught in standard commercial crab traps fished in 15-25 ft of water from both sides of Kiket Island. All crabs were held for at least 24 hr in ambient sea water in troughs identical to the gradient trough, except for the plumbing. The holding tanks were illuminated by normal room lighting, but the gradient trough was shielded from room lights and laboratory activity by sheets of black polyvinyl (Visqueen) plastic.

Each test crab was fitted with a hydrographic temperature probe (Model L5U-SF). A rubber strap hooked over the most posterior teeth of the carapace margin held the probe in place across the top of the carapace. The strap was stretched firmly across these points. At each end of the gradient another probe was placed for measurement of the maximum and minimum temperatures in the gradient throughout the experiment. All probes were monitored by an electronic thermometer (ARA-ET 100A), a 20-input channel programmable scanner (ARA-SD20), and a strip chart recorder (ARA-400). The scanner dwell time was set at 40 sec during the experiment. A complete set of temperatures in the gradient (inflow, outflow, and crab temperatures) in addition to offshore water temperatures were recorded every 4 minutes.

The experiment was begun by calibration of each probe reading with a standard mercury thermometer. The gradient manifold was thoroughly flushed. The two crabs to be used were fitted with a probe and placed in the compartments separated by the gradient manifold and the vinyl-coated wire fence. The black plastic curtain was fixed in place, and the recordings were begun. The standard length of an experiment was 24 hr. This interval usually spanned a complete tidal cycle of two highs and two lows. This was an attempt to average the effect of normal salinity changes caused by tidal conditions, since salinity was an uncontrollable experimental variable. All crabs used in the experiment were of legal size or greater (15.6-17.5 cm).

10.3.3 Results

Fifteen 24-hr experiments were run during the period of July 7 to August 24, 1971, and five experiments in the period of April 10 to April 15, 1972. The results of five of the 15 experiments during the summer were not considered because of malfunction in the experimental apparatus. In three of these cases, the self-regulating warmwater mixing valve malfunctioned during the experiment. In the two other experiments omitted, one or both of the crabs became tangled in their probe lines. This problem proved to be one of the major shortcomings of the experimental setup. Throughout subsequent experiments, the crabs were checked periodically to assure that the crabs' movements were not restricted by tangled lines.

The mean minimum and maximum temperature ranges in the gradients and the respective mean temperature choices of the test crabs in the experiments are summarized in Table 10-1. The results are based on a total of 360 hr of observations with one set of observations recorded every 4 minutes. Examples of the results from frequency analysis of an experiment from the summer period and winter period are shown in Figs. 10-9 and 10-10. Also shown are the mean, maximum and minimum with standard deviations of the temperatures in the gradient trough. An analysis of temperature variance in the summer experiments showed that the variance of the four temperatures recorded in each experiment was greater than the variance in temperatures between the experiments. This predictable result was based on temperature fluctuations in the gradient due to changes from tidal stage in ambient water temperatures. In all cases during the summer experiments the mean temperatures recorded for each crab replicate differed significantly from the mean maximum and minimum temperatures in the gradient. This difference indicated that the crabs were selecting a preferred temperature within the gradient temperature range. An analysis of variance of the temperatures recorded for the crabs showed there was significantly more variance within the experiments than between experiments. The greater variance in the temperatures recorded for each crab during an experiment was due to the exploratory behavior of the crabs. As seen in Fig. 10-10, each crab spent some time in short excursions to the warm end of the gradient. Although the exact reason for this behavior is uncertain, it was observed to occur most often during a low tide. The behavior may have been in response

Table 10-1. Mean, minimum, and maximum temperature ranges in gradients and mean temperature selection of crabs in a thermal gradient

Summer trial	Date	Minimum temperature $\bar{x}$	SD	Crab No. 1 $\bar{x}$	SD	Crab No. 2 $\bar{x}$	SD	Maximum temperature $\bar{x}$	SD
1	6/10/71	11.8	1.2	13.2	2.3	13.0	2.0	18.5	0.3
2	6/12/71	10.8	1.4	12.9	1.9	13.1	1.7	18.9	0.5
3	6/20/71	11.2	1.0	14.0	1.7	13.6	1.9	18.1	0.6
4	7/15/71	11.3	1.3	13.3	1.8	13.2	1.7	18.5	0.8
5	7/17/71	11.0	1.2	13.0	1.8	13.2	2.7	18.6	0.8
6	7/20/71	12.0	1.8	14.1	3.2	13.1	1.8	19.1	0.4
7	7/24/71	12.0	1.9	12.6	1.9	13.3	1.5	18.2	0.7
8	8/10/71	11.3	2.0	13.6	2.5	14.6	2.4	19.1	1.1
9	8/13/71	11.1	0.8	12.6	1.9	13.8	2.3	19.0	0.5
10	8/15/71	11.4	1.1	12.9	2.2	13.3	2.0	19.3	0.9
	$\bar{x}$	11.4		$\bar{x}$ 13.2		$\bar{x}$ 13.4		$\bar{x}$ 18.7	

Winter trial	Date	Minimum temperature $\bar{x}$	SD	Crab No. 1 $\bar{x}$	SD	Maximum temperature $\bar{x}$	SD
1	4/13/72	11.1	0.6	12.6	0.7	14.3	1.2
2	4/14/72	9.3	0.3	9.4	0.7	18.9	0.7
3	4/15/72	9.7	2.3	11.9	0.5	18.7	0.7
4	4/20/72	9.4	1.8	11.2	0.7	18.8	0.3
5	4/21/72	9.6	0.9	11.8	0.5	18.1	0.4
	$\bar{x}$	9.8		$\bar{x}$ 11.4		$\bar{x}$ 17.8	

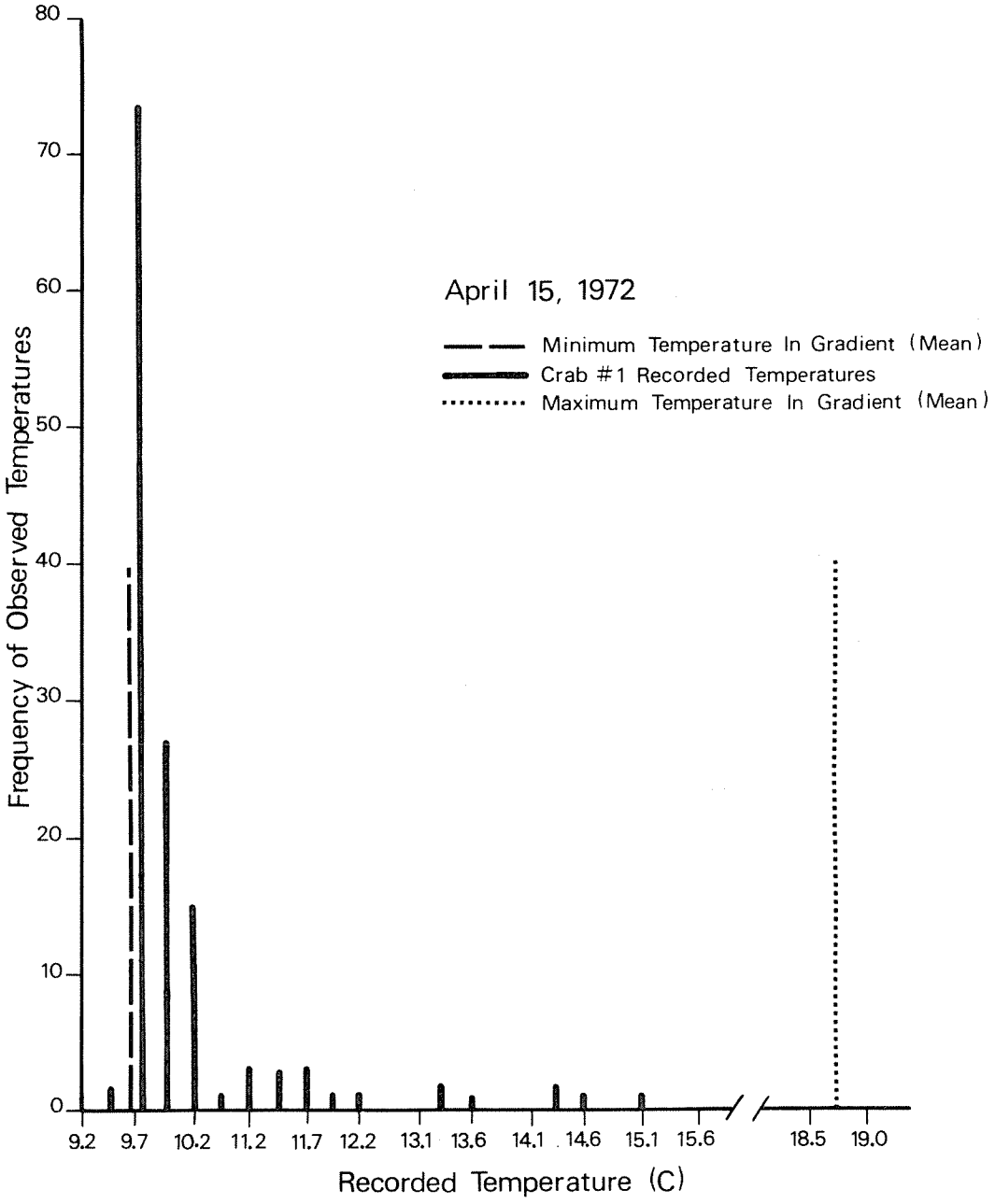

Fig. 10-9. A spring month example of the temperatures (C) recorded during 10 hr of observations of *Cancer magister* and the minimum and maximum temperatures in the thermal gradient.

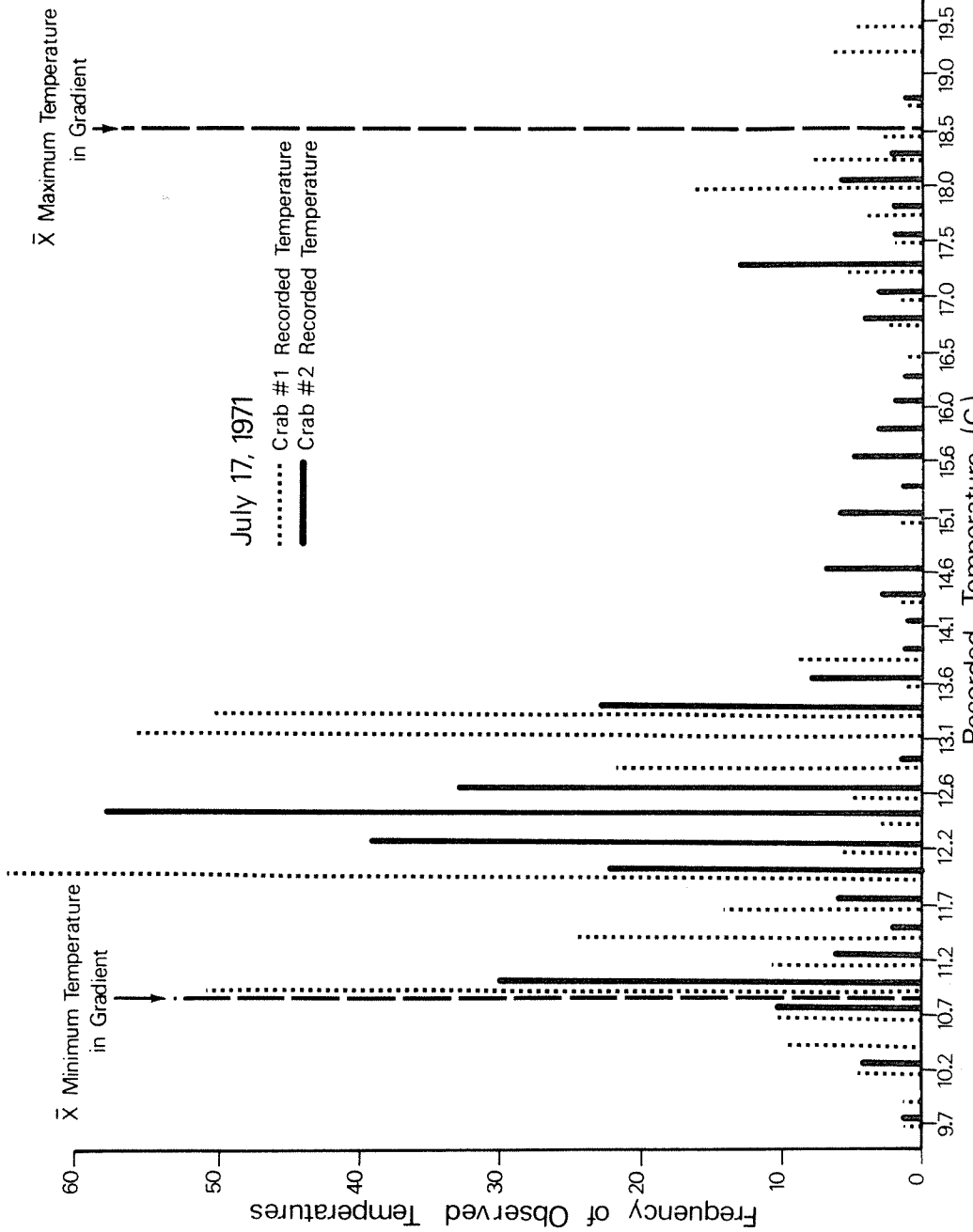

Fig. 10-10. A summer month example of the temperatures (C) recorded during 24 hr of observations of *C. magister* and the minimum and maximum temperatures in the thermal gradient. Mean maximum and minimum gradient temperatures are included.

to decreasing salinities. Crabs are very thigmotactic, and the test crabs may have been responding to a visual cue at the corners or end of the trough. However, since the crabs spent most of their time in the midportion of the trough, these behavioral traits seem to have little affected the results. Prior to the July 17, 1971 experiment test crabs were placed in ambient water in the gradient trough. The trough was divided into fourths. The crabs were scored every 15 minutes over the next 6 hr for the number of times they were seen in each of the four sections. The results of a chi-square analysis showed that there was no significant difference in the number of times a crab was found in each section and the number of times expected with a probability of 0.25. When large numbers of crabs were held in a similar trough, they were commonly observed to gather at one or the other end of the trough. However, since the crabs spent the majority of their time in the midportion of the trough during the thermal gradient experiments, the "corner or end effect" appears to be of secondary importance. It might be that the escape or defense response of retreat to the end corners was elicited by the visual presence of other crabs. In the thermal gradient environment, the test crab was isolated. In addition, the gradient experiments were conducted in the dark. Crabs observed in the holding tank were under normal laboratory lighting.

The mean temperature recorded during the summer period for 20 crabs throughout 240 hr of experiments was 13.3 C. The standard deviation of the experimental means from the overall mean of 13.3 C was $\pm$ 0.5. The overall mean temperature recorded during the winter experiments for 15 crabs in 120 hr of observations was 11.4 (SD = 1.21). The summer and winter means were significantly different at the 99 per cent confidence level when compared with a "student's t-test."

10.3.4 Discussion

The results from both summer and winter experiments demonstrate a temperature preference among the crabs tested. The preferred temperature changed from one experimental period to the next; this change indicates a seasonal shift in temperature preference. The decline in preferred temperature corresponded to a decline in ambient salinity, temperature, and photoperiod. The results of the experiments do not permit isolation of the roles of primary

variables responsible for change in the crab's temperature preference. The pattern does suggest, however, an interesting area for further studies in crab behavior under more rigorously controlled experimental conditions.

Thermal avoidance is clearly seen in the pattern of temperature frequency distributions. During the summer experiments only rarely were crabs recorded in temperatures above 15.5 C, except those occasions when the crabs were apparently attracted to the cover provided by the corners at the warm end. During the winter experiments, no crabs were recorded in temperatures above 15.1 C. Avoidance behavior at elevated temperatures was most apparent during the winter trials. This response may have been due to an increased thermal sensitivity brought about by changes in the winter environment or a physiological condition of the crabs. Whatever the cause for increased avoidance behavior, it seems conclusive that crabs will more uniformly avoid elevated temperatures during the winter periods than the summer. The preferred summer and winter temperatures represent nearly equal Δt's over ambient conditions. The difference between average ambient conditions and the crabs' summer and winter mean preferred temperatures was 1.8 C and 1.6 C, respectively.

It seems likely that at low Δt's (2 C) above ambient conditions, crabs would be attracted to warmer regions. Increase in the Δt above this level would increasingly produce an avoidance reaction. During winter a Δt discharge of more than 6 C would exclude crabs from the area. During summer a Δt above 7 C would tend to exclude crabs from the area. However, since crabs appear less sensitive to elevated temperatures during this period than winter, they may continue to use the affected area in search of food and/or cover.

10.4 RESPONSE OF MARINE FISH IN A THERMAL GRADIENT

by

Q. J. Stober and T. J. Northup

10.4.1 Introduction

The behavioral response (attraction or avoidance) of the Skagit Bay marine fish community to a well-defined thermal plume discharged from a power plant is not presently predictable. Very little experimental work to determine the behavioral response of Pacific marine fishes to sublethal thermal exposure has been conducted; however, recent behavioral studies of Atlantic estuarine fishes (Meldrim and Gift, 1971; Gift and Westman, 1971) have been reported. Fish abundance has been reported in the discharge plume of some thermal power plants (Allen et al., 1970; Elser, 1965). In some cases, excellent recreational fishing occurs in the discharge canal or near the thermal plume. The waters of Skagit Bay have consistently low ambient water temperatures, and if a local area were warmed by the discharge of heated water, it could be assumed that some species would find conditions more favorable and be attracted into the warmer waters while others might be repelled. Eurythermal species might be attracted, provided the food supply were adequate and become established in the local area of the discharge. In some cases fish would be attracted simply by the physical placement of new structures (i.e., pipes, breakwaters, etc.) underwater since these would provide additional habitat. Two of the more abundant pelagic species, surf smelt (*Hypomesus pretiosus*) and Pacific herring (*Clupea harengus pallasi*), and benthic species, starry flounder (*Platichthys stellatus*), were selected for a preliminary investigation of their behavioral response if exposed to a unidirectional thermal gradient. In these experiments a thermal situation was tested that was much more extreme than predicted by Bendiner et al. (1971) from in-situ dye simulation studies for a once-through cooling system. The hydrodynamics of North Skagit Bay are very complex and extremely difficult to duplicate in the laboratory. Therefore, in these tests the hydrodynamics were simplified into a unidirectional thermal gradient with sublethal temperatures ranging to about 10 C above ambient, a condition worse than predicted for the Bay.

10.4.2 Materials and Methods

Specimens of the three species tested were obtained in the bays adjacent to Kiket Island. Surf smelt and starry flounder were captured with a 100-ft (30.5 m) beach seine. Herring were obtained with an experimental purse seine 274.3 m (150 fm) long by 9.14 m (5 fm) deep. All test fish were transported to the laboratory on Kiket Island and held in tanks under ambient conditions for several days prior to testing.

The onsite thermal effects laboratory was described by Stober (1972). The experimental apparatus used in these tests is illustrated in Fig. 10-11. Two parallel gradient troughs were constructed of 1.9-cm fiberglass-coated plywood, each with inside dimensions of 243.8 cm (8 ft) long by 14.9 cm (5-7/8 inches) wide x 23.5 cm (9-1/4 inches) deep, [21.0 cm (8-1/4 inches) to diffuser]. A 111.8-cm diameter (44 inches) gradient holding tank, 35.6 cm deep (14 inches) modified plastic wading pool was attached to one end of the parallel troughs to hold the fish prior to testing. Water in the gradient holding tank was 24.8 cm deep (9-3/4 inches). The effective length of each trough was 182.9 cm (6 ft) divided into 10 equal sections. A fish entry area at the inlets was screened off with 1.27-cm-mesh (1/2 inch) vinyl-coated wire at the trough end, as well as 45.7 cm (18 inches) toward the outlet at the beginning of section 1. An additional 1.27-cm- (1/2 inch) mesh wire screen was used to separate section 10 from the outlet area. The interior of the trough was painted a light green with contrasting lines for the demarcation of the ten section boundaries.

A diffuser of 0.635-cm (1/4 inch) plexiglass perforated with 0.24-cm (3/32 inch) holes on 0.95-cm (3/8 inch) centers was placed 2.54 cm (1 inch) above the bottom of the troughs. Six rows of 0.635-cm (1/4 inch) port openings were mounted below the diffuser in groups of three. The first row of ports were spaced beginning 22.9 cm (9 inches) from the outlet end of the test trough. Successive groups of ports were located 38.1 cm (15 inches), 61.0 cm (24 inches), 91.4 cm (36 inches), 129.5 cm (51 inches), and 175.3 cm (69 inches) proceeding toward the inlet. Outside ports were 2.38 cm (15/16 inch) from the walls of the trough and separated 5.08 cm (2 inches) from the center port. The ambient trough ports were placed at the same intervals, except that they were offset 1.27 cm (1-1/2 inches) toward the inlet. Dual manifolds constructed of PVC pipe supplied heated and ambient sea water to the troughs.

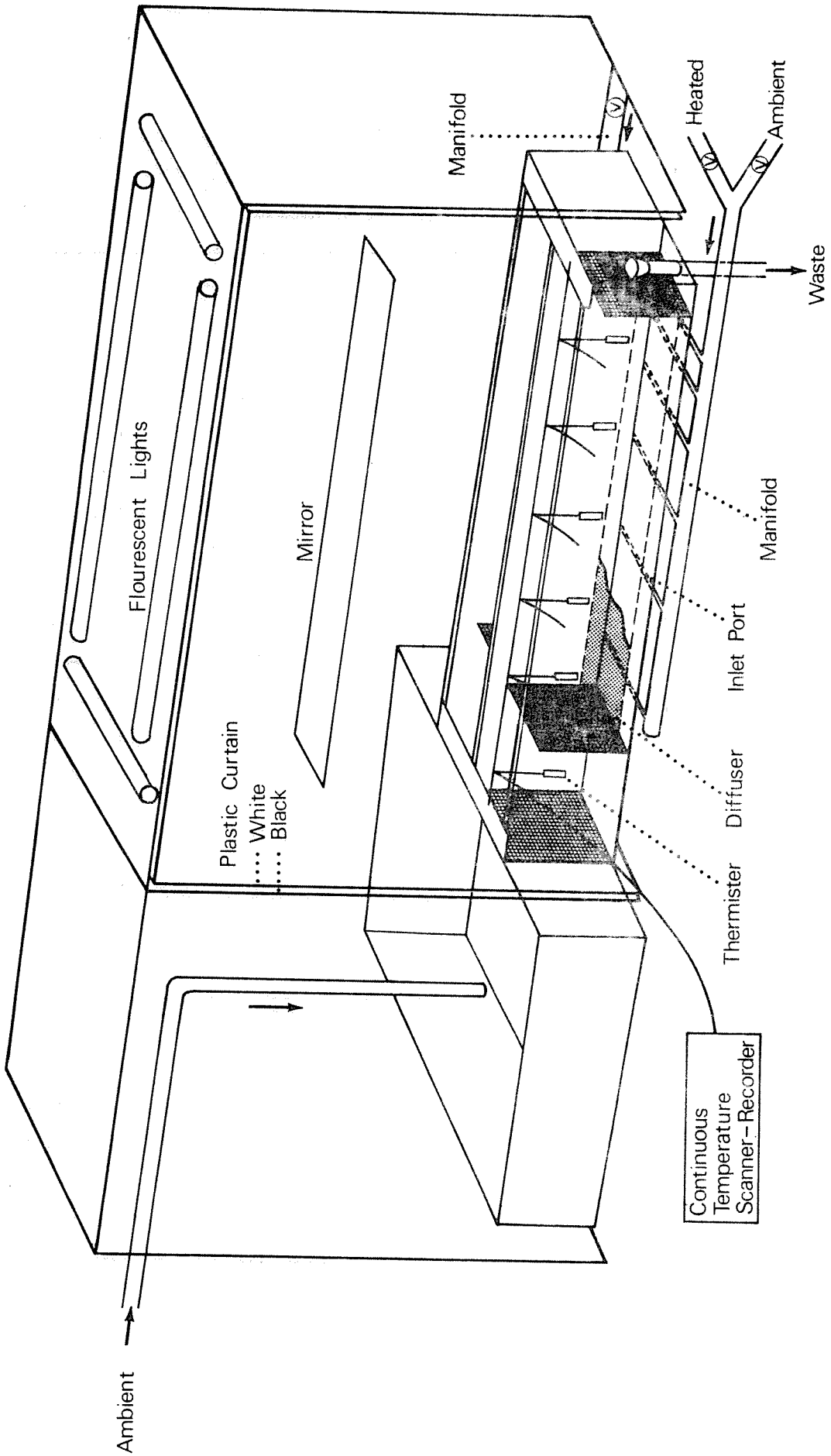

Fig. 10-11. Isometric view of the dual thermal gradient test apparatus.

The manifold consisted of a 3.8-cm (1-1/2 inch) main line, 1.9-cm (3/4 inch) supply lines to each group of three ports, and three 1.27-cm (1/2 inch) standpipes that directed water through the 0.635-cm (1/4 inch) ports mounted in the tank bottom. The diffuser fitted in each trough effectively distributed the water introduced through the ports. The manifold that supplied the control trough introduced ambient water, while the manifold that supplied the test trough supplied either ambient or heated sea water. The heated sea water was drawn directly from the laboratory heat exchanger, through the temperature-control mixing valve and supplied directly to the test trough manifold. Ambient water was supplied from the laboratory head tank.

Ambient sea water was continuously introduced into the gradient holding tank so that a constant positive current was provided through the troughs. An outlet discharge of 52.2 ℓ/min (13.8 gpm) through each trough was maintained by adjustment of the flow to the holding tank and that through each manifold with control valves. The introduction of heated sea water through the test trough manifold created a thermal gradient in which temperature increased from inlet to outlet and a maximum Δt of about 10 C was obtained in section 10. Water overflowed from each trough through an expanded 2-inch-diameter downspout 12.1 cm (4 3/4 inches) high. The effective water depth above the diffuser surface was maintained at 9.53 cm (3 3/4 inches).

A black plastic sheet (Visqueen) was hung around the behavior tank and gradient holding tank to exclude extraneous lights and movements of the experimenter from the view of the test animals. It enclosed a 101.6- x 243.8-cm area (40 inches x 96 inches). A white plastic sheet was hung on the inside of the black sheet to aid in lighting the troughs. The top of the enclosure was covered with white plastic sheeting.

Lighting was provided by two 121.9-cm-(4-ft) and two 61-cm-(2 ft) long fluorescent lamp fixtures each containing two lamps, mounted approximately 134.6 cm (53 inches) above the troughs. The lights were mounted symmetrically above the tank so that the long lamps paralleled the long sides and the short lamps the ends of the enclosure. Lamps utilized were 40 W Gro-lux Vita Lite, a fluorescent light most closely resembling natural sunlight. A Grossen Luna-Pro light meter was utilized to measure a uniform brightness of approximately 86 (8 ft-C) lumen/m^2 over the length of both troughs.

A mirror 24.1 cm (9 1/2 inches) was hung 76.2-83.8 cm (30-35 inches) 50.8-58.4 cm (20-23 inches from ceiling to mirror) above the troughs at an angle so that the fish could be observed from a position beside and below the plane of the troughs. All attachment devices and power cords were covered with white plastic or painted white so that the possibility of presenting orientation cues to the test animals would be minimized.

Hydrographic temperature probes (Model L5U-SF) were suspended in sections 0 (fish entry area), 2, 4, 6, 8, and 10 in each trough approximately 2.54 cm (1 inch) below the water surface. An electronic thermometer (ARA-ET 100A), a 20-input, programmable scanner (ARA-SD20), and a strip chart recorder (ARA-400) continuously monitored temperatures at 15-minute intervals in the six sections of each trough.

Dye tests were run before each test in both troughs prior to introduction of the fish. The dye was introduced and timed with a stop watch through each of the 10 sections for determination of the velocity gradient and flow pattern through both troughs.

Prior to testing approximately ten fish were transferred from a laboratory holding tank to the gradient holding tank attached to the troughs. A 3-day period of acclimation was allowed for recovery from the effects of handling before testing began. The sequence of preparation prior to a test included calibration of the flow rates in each trough and activation of the temperature-monitoring instruments. One fish was moved into position between the screens at the inlet to each trough without handling, and when the experiment was begun was released into its respective trough by lifting of the second screen. An elapse time meter was then activated. Ambient water was allowed to flow through both trough manifolds during the first 15 minute of each test; after that time the ambient water was replaced with a flow of heated water through the manifold in the test trough. It took an average of 49.1 sec for the thermal gradient to become fully established at a maximum Δt of 11.9 C. Behavioral observations were made during the first 14 min at ambient temperature and then continued for the succeeding 46 min with the test gradient in operation. The position of the head of each fish in each trough was recorded by the observer at 15-sec intervals for smelt (except 20 pairs of smelt were observed only once per minute) and herring and at 1-minute intervals for starry flounder. All fish were experimentally naive and were released after each test.

Thermal resistance tests were conducted on Pacific herring as described in preceding annual reports.

Salinity samples were taken during each experiment and analyzed by the University of Washington Department of Oceanography. Dissolved oxygen content in both ambient and heated sea water was determined for each experiment by the modified Winkler method. Ambient and gradient temperature data recorded on strip charts were analyzed for the combined tests for each species.

10.4.3 Results and Discussion

Behavioral experiments were conducted from December 31, 1971 to February 18, 1972 on surf smelt. Fifty pairs of surf smelt were tested. All observations (140) were summed and averaged so that a mean value was obtained for each occupied section for the test and control fish each minute. Mean section values for test and control were plotted (Fig. 10-12) for each of the 60 test minutes. A linear regression analysis of these points for both groups was conducted for minutes 1 to 14 and 15 to 60, the preheat and postheat injection periods, respectively. An analysis of covariance of the mean section values per minute for both test and control fish before and after the injection of heat indicated that a significant avoidance (.01) of the test fish occurred after the application of heated water. The slope of the regression after heat injection was negative (-0.0482), indicating a movement toward the inlet end of the gradient and lower temperatures. The regression on control means indicated a positive slope (0.0110). The test fish selected temperatures between 11.5 and 12.5 C (Fig. 10-12), temperatures 4.5 to 5.5 C above ambient. The velocity gradient was greater than the threshold of 20 cm/min reported by Bull (1935) to excite the rheotaxis of fish. However, the velocity gradients were nearly identical in both troughs, Fig. 10-12. The average length of test fish was 137.6 mm (SD = 16.4), as compared to that of 138.6 mm (SD = 16.0) for the controls. Salinity ranged from 21.5 to 29.5 ppt during the test period.

Fifty pairs of Pacific herring were tested from July 24 to August 28, 1972. Observations made at 15-sec intervals were summed and averaged and a mean occupied section value for the test and control fish obtained. Mean section values for test and control fish were plotted (Fig. 10-13) for each of the 60 test minutes. A linear regression analysis of these points for both

Surf Smelt, 1972

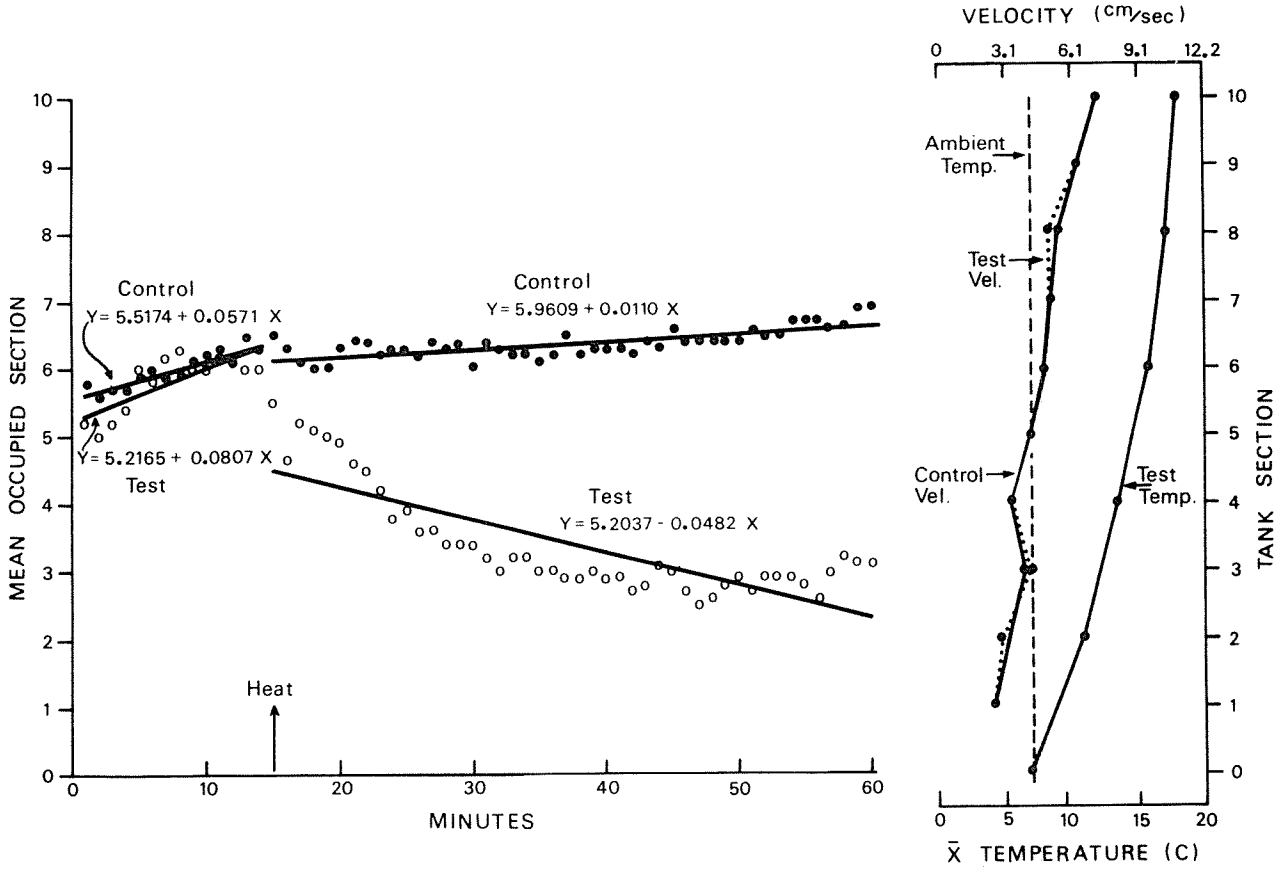

Fig. 10-12. Mean section values for test and control surf smelt for each of 60 min of observation, heated water was introduced after 15 min. The temperature and velocity gradients are illustrated.

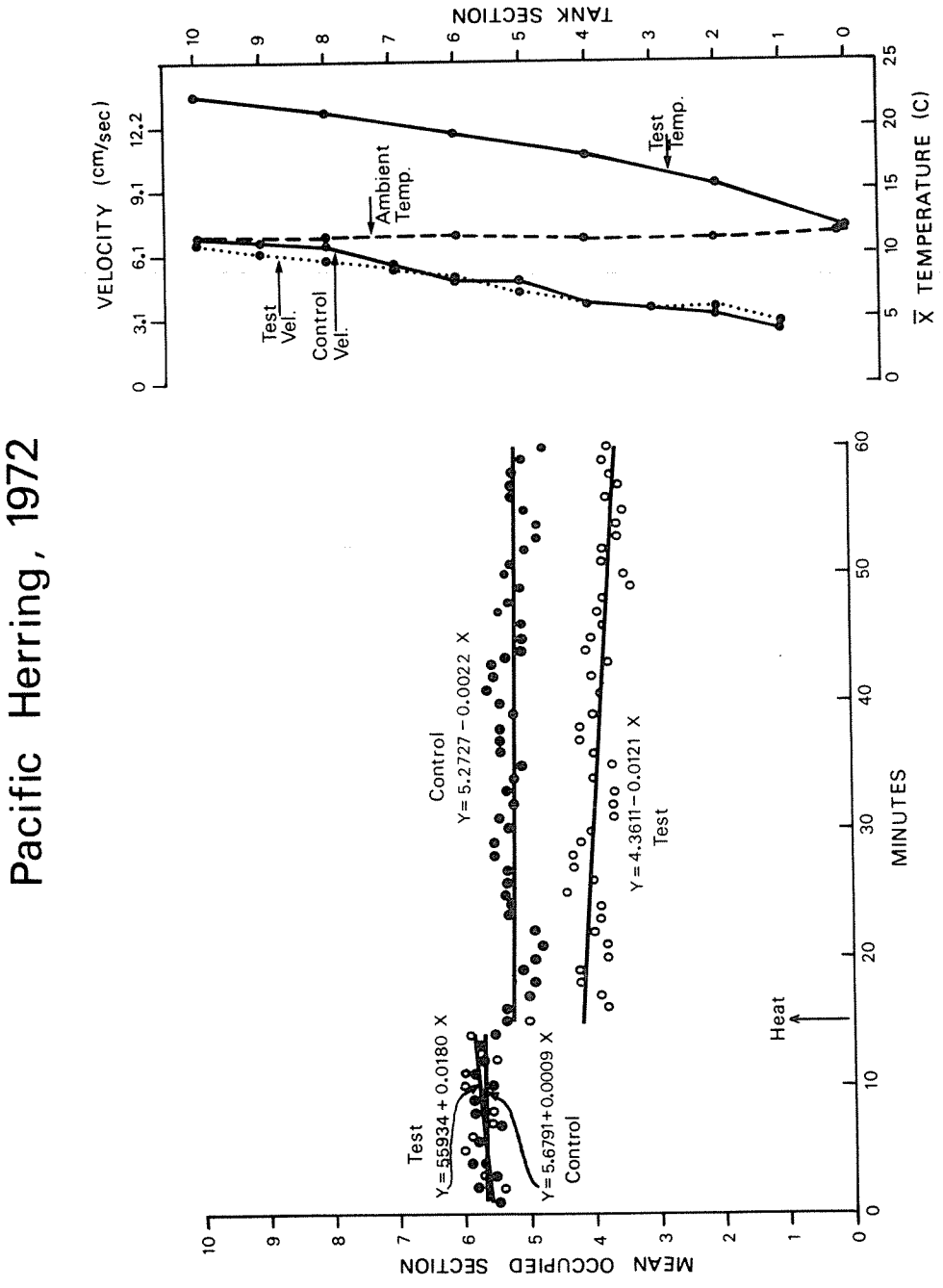

Fig. 10-13. Mean section values for text and control Pacific herring for each of 60 min of observation, heated water was introduced after 15 min. The temperature and velocity gradients are illustrated.

groups was conducted for minutes 1 to 14 and 15 to 60, the preheat and postheat injection periods, respectively. An analysis of covariance of mean section values per minute for both test and control fish before and after the injection of heat indicated that a significant avoidance (.01) of the test fish occurred after the application of heated water. The slope of the regression after heat injection was negative (-0.0121), indicating a movement toward the inlet and lower temperatures. The regression on control means was only slightly negative (-0.0022) and did not appear to indicate a significant movement in either direction. The test fish selected temperatures between 17 and 18 C, temperatures 5.5 to 6.5 C above ambient.

The average length of test fish was 131.5 mm (SD = 28.4) and that of the controls was 131.0 mm (SD = 27.8). Salinity ranged from 24 to 30.5 ppt during the test period.

Thermal resistance tests were conducted on August 29, 30, and 31, 1972, on a total of 79 Pacific herring (mean standard length = 108.4 mm, SD = 11.5) at temperatures of 24 and 25 C. Continuous-flow thermal tolerance tests were conducted at 23 C, but less than 50 per cent mortality was observed in a 24-hr period. The geometric mean times to EL and death at 24 C were 172.3 minute and 250.8 minute, respectively, and at 25 C 17.3 minute and 29.2 minute, respectively. The 24-hr incipient lethal temperature was 24 C. The mean ambient temperature during these tests averaged 11.6 C, a Δt of 12.4 C.

The behavior of 49 paired starry flounder was tested from January 25 to March 22, 1972. The observations were summed and averaged so that mean occupied section values were obtained for the test and control fish. Mean section values were plotted for test and control fish (Fig. 10-14) for each of the 60 test minutes. A linear regression analysis of these points for both test and control groups was conducted for minutes 1 to 14 and 15 to 60, the preheat and postheat injection periods, respectively. An analysis of covariance of the mean section values per minute for both test and control before and after the injection of heat indicated a significant (.01) difference between the response of the test and control fish after heat injection. The slopes of the regression lines before and after heat injection were all negative and nearly parallel; thus interpretation was difficult. The test fish consistently occupied sections closer to the inlet than the control fish;

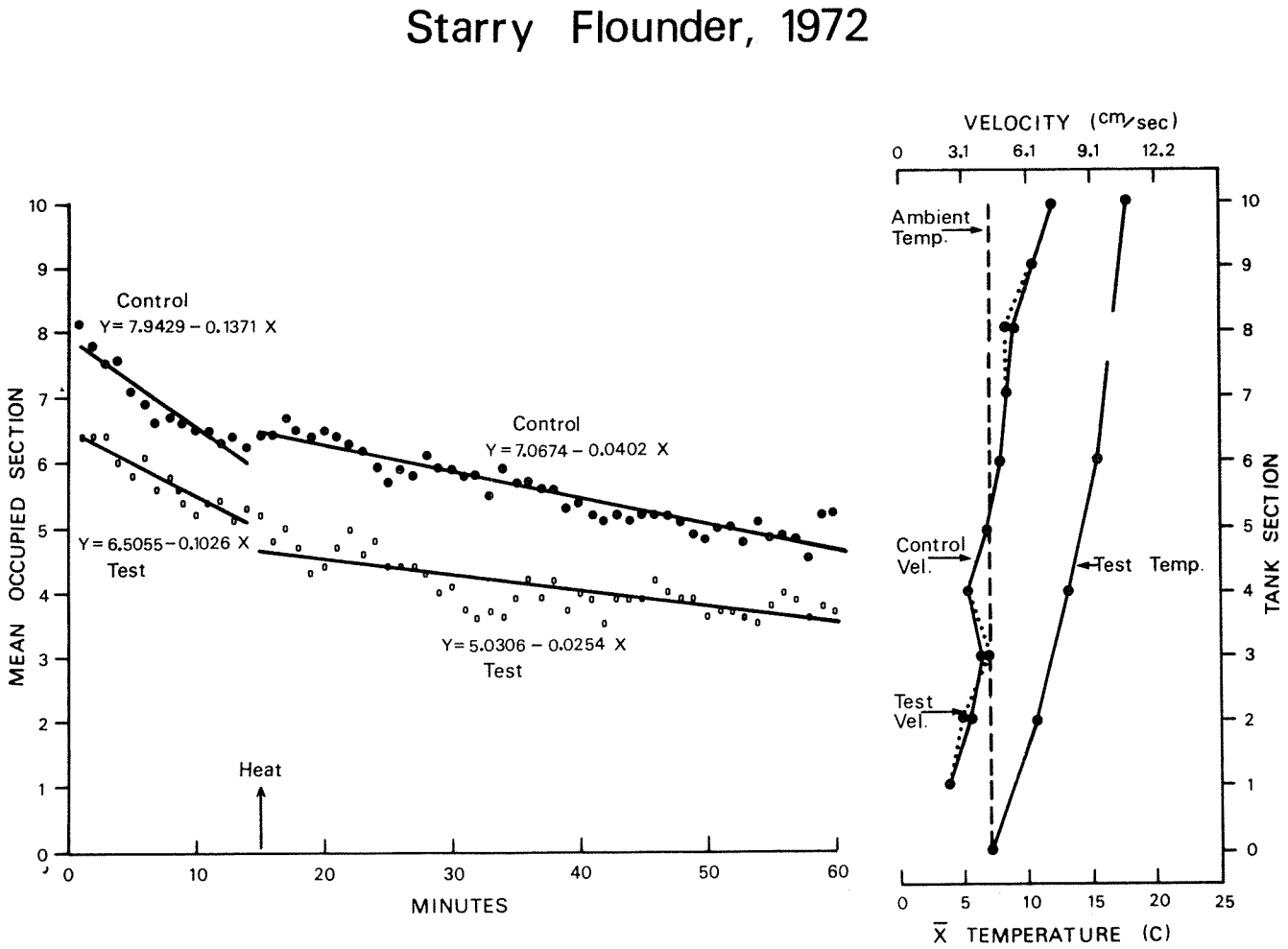

Fig. 10-14. Mean section values for test and control starry flounder for each of 60 min of observation, heated water was introduced after 15 min. The temperature and velocity gradients are illustrated.

however, these results probably indicate that the technique used does not adequately test this species. Since this species occupies a benthic habitat where water velocities are characteristically lower, the relatively high experimental water velocities may have stimulated a negative rheotactic response.

The average length of test fish was 99.6 mm (SD = 40.7), and that of the controls was 99.7 mm (SD = 40.1). Salinity ranged from 19.0 to 29.5 ppt during the test period.

10.4.4 Summary and Conclusions

A study of the behavior of three resident marine species cannot provide enough information to allow prediction of the attraction or avoidance reactions that may be exhibited by the entire marine fish community; however, some relationships are apparent. Bendiner et al. (1972) predicted that a field of plumes would result due to tidal mixing with characteristic scales of 50-1,500 m horizontally and 2-30 m vertically and six hours or less in duration. Typical maxima could be reduced by a diffuser discharge design.

In these experiments the test fish were presented with a thermal gradient much higher than predicted and those of pelagic species (smelt and herring) were observed to avoid maximum temperatures. Surf smelt selected temperatures between 11.5 and 12.5 C (4.5 to 5.5 C above ambient). Pacific herring selected temperatures between 17 and 18 C (5.5 to 6.5 C above ambient). The 24-hr incipient lethal temperature for herring occurred at 24 C, 12.4 C above ambient temperature. Tests were inconclusive on starry flounder. Considering the predicted excess temperatures of 2-3 C as the extreme, we find that surf smelt and herring selected Δt's greater than those predicted by *in situ* dye studies. The behavioral response to a more subtle gradient, with maximum temperatures of only 2-3 C or less, should be determined in future tests.

10.5 SUMMARY AND OVERVIEW OF EXPERIMENTAL THERMAL EFFECTS STUDIES

by

Q. J. Stober

A variety of experimental studies on thermal effects were conducted in the on-site laboratory described by Stober, (1972). These studies dealt with certain species, both anadromous and resident, that characteristically inhabit the pelagic and demersal areas of the bays surrounding Kiket Island (Stober and Salo, 1970 and 1971). The overall objective was to develop information useful in evaluating the biological significance of the thermal effects predicted to occur with a once-through cooling system. This research was directed toward determining the behavioral responses of these fishes to thermal shock and thermal gradient conditions that could occur with the circulation of 1,500 cfs increased approximately 10 C in temperature.

10.5.1 Pelagic Species

10.5.1.1 Salmonids

The abundance of migrating anadromous juvenile salmonids in North Skagit Bay each spring and summer and their high economic importance required a major effort on these species. These anadromous fishes are the major pelagic species during the time of passage. Thermal tolerance to acute lethal temperatures was determined for pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and chinook (*O. tshawytscha*) salmon, including times to equilibrium loss and death. In all instances, thermal tolerance was found to be greater than 10 C above the ambient temperature; therefore, predation experiments were conducted for assessment of potential sublethal effects ranging from ambient to the lower lethal temperature. The behavioral response (Bessey, 1972) of these juvenile salmonids was then investigated in a horizontal moving thermal gradient so that predictive information would be obtained on the ability of salmon to detect, choose, or avoid various temperatures. Wild fish were tested in all cases except chinook salmon, which were obtained from the Skagit Hatchery.

Thermal resistance tests conducted on pink, chum, and chinook salmon during 1970-71 showed that lethal temperatures ranged from 24-29 C in 1970 and from 23-29 C in 1971. Ambient water temperatures averaged 1.5 C lower during testing of juvenile salmonids in 1971 than in 1970. All species showed similar resistance times, but pink and chum salmon had a more rapid response time (lower tolerance) to equilibrium loss (EL) and death than chinook tested during both years. The shift of the incipient lethal temperature from 24 C in 1970 to 23 C in 1971 was probably due to lower ambient temperatures to which the fish were acclimated during 1971.

We designed predation tests to determine whether thermal effects occurred at sublethal temperatures below the acute lethal limit. Initial tests were conducted in 1970 for determination of differential predation, if any, between "stressed" and control pink, chum, and chinook salmon. A series of arbitrary stress times ranging from zero to 1,440 minute were tested at ambient temperature (10 C) and at 15, 17.5, 20, 22.5, and 25 C. A sublethal effect was suggested at 20 C and above for pink-chum tests; however, an unavoidable additional stress due to handling may have confounded the results. Predation tests on chinook salmon indicated that differential effects were not likely below 20 C. Similar tests in 1971 on juvenile chum salmon again were confounded by a handling stress; however, the ratios calculated on totals at each stress temperature failed to indicate a consistent increase with increase in stress period at 21.5 C and at greater than the 20 per cent median equilibrium loss dose at 23 C. Sublethal thermal effects below 21.5 C were doubtful. Predation tests on chinook salmon illustrated conclusively that sublethal thermal effects did not create an effect of ecological significance below 21.5 C, but that an exponential increase in the behavioral response occurred above this temperature. The ambient temperature during all predation tests averaged 10 C. Lethal or sublethal thermal effects would not be likely to occur on juvenile pink, chum, or chinook salmon if a 10 C temperature increase were imposed during migration through North Skagit Bay.

The behavioral responses of juvenile salmonids were determined for wild and hatchery-reared chum, wild pink, and hatchery-reared chinook salmon in a moving horizontal thermal gradient constructed in the Kiket Island laboratory. Behavioral tests were conducted in a dual thermal gradient

trough that permitted simultaneous observation of fish behavior at ambient and increased temperatures.

The minimum temperatures consistently avoided by the fish groups were: wild chum, 16.0 C; hatchery-reared chum, 15.0 and 16.5 C; hatchery-reared chinook, 16.0 and 16.5 C; and wild pink salmon, 19.0 C. Pink salmon were delayed past the normal time of migration approximately 2 months prior to testing. The minimum temperature increase that caused significant avoidance by wild chum was 1.6 C; that for hatchery-reared chum was 1.8 and 7.0 C; that for hatchery chinook was 6.2 and 8.6 C; and that for wild pink salmon juveniles was 8.7 C.

Juvenile chum and pink salmon schooled closely and were in constant motion under ambient temperature conditions. Juvenile chinook salmon did not display strong consociation and moved slowly or were motionless in ambient temperature sea water. All species responded immediately to a temperature increase of less than 1 C per minute by demonstrating increased swimming rates, preference for regions with near-ambient temperatures, and a decreased consociation within schools. There was generally little or no response to a temperature increase greater than 1 C per minute until gradient temperatures approached 20 C. It is clear that juvenile salmonids will avoid areas of increased temperature.

10.5.1.2 Resident Species

The resident pelagic species tested were the shiner perch (*Cymatogaster aggregata*), surf smelt (*Hypomesus pretiosus*), and herring (*Clupea harengus pallasi*), the most abundant species in North Skagit Bay. The tolerance to lethal temperatures was determined for all and the behavioral avoidance response to increasing temperatures in a standing thermal gradient was determined for surf smelt and herring. Upper lethal temperatures ranged from 21 to 25 C for surf smelt tested between December 14, 1970 and February 24, 1971, during which the ambient water temperature averaged 7.1 C. Surf smelt exhibited the lowest thermal tolerance of all species tested. Their low tolerance was partly a result of low winter ambient temperatures to which they were acclimated as well as the delicate nature of the species and difficulty of testing in the laboratory. Behavioral tests in a dual thermal gradient trough indicated a strong avoidance response. Surf smelt selected temperatures between 11.5 and 12.5 C,

temperatures 4.5 to 5.5 C above ambient, when exposed to a gradient with a maximum Δt of 11.9 C.

Thermal resistance of juvenile shiner seaperch was tested from August 10 to September 8, 1971. Upper lethal temperatures ranged from 26.5 to 30 C, whereas the ambient temperatures reached a maximum average of 12.8 C. This species is found intertidally in dense schools near shore during July, August, and September where maximum seasonal water temperatures prevail. Its high thermal tolerance is therefore consistent with its behavioral ecology.

Pacific herring tested in late August 1972 indicated a 24-hr incipient lethal temperature of 24 C, a Δt of 12.4 C above ambient temperature. Behavioral tests in a dual thermal gradient trough indicated an avoidance response to increased temperatures. Pacific herring selected temperatures between 17 and 18 C, temperatures 5.5 to 6.5 C above ambient, when exposed to a gradient with a maximum Δt of 11.9 C.

10.5.2 Benthic Species

10.5.2.1 Bottom Sediments

The effects of temperature on rates of oxygen uptake by subtidal bottom sediments were tested. Heated sea water was circulated through the water column above sediment cores collected from the Bay. These experiments demonstrated the relationship between water temperature and the rate of sediment oxygen consumption. The mean ambient summer consumption rate was 12.43 ml O_2 hr^{-1} m^{-2} with a range of 6.86 to 20.32 ml O_2 hr^{-1} m^{-2}. The mean ambient winter consumption rate was 6.79 ml O_2 hr^{-1} m^{-2} with a range of 3.62 to 9.51 ml O_2 hr^{-1} m^{-2}. The difference between the mean rates of O_2 uptake during the summer and winter was significant at the 99-per cent level.

The rates of O_2 uptake plotted against temperature showed a steady increase up to temperatures around 23 C. Uptake accelerated with temperature increases beyond 23 C up to 28-29 C, then declined. The drop in the respiratory rate in the region of 28-30 C corresponds to the region of observed mortality in heat-treated cases. The shift in Q_{10} in the 23-25 C region may represent the area where sublethal temperature effects exceeded the organisms' capacity for physiological accommodation.

10.5.2.2 Invertebrates

The resistance to lethal temperatures of the opossum shrimp (*Neomysis awatschensis*) was tested between September 13 and October 5, 1971 in 48-hr continuous-flow bioassays. The 48-hr TL50 occurred at about 23 C while ambient water temperatures during the tests ranged from 10.4 to 11.9 C.

The thermal tolerance of Dungeness crab (*Cancer magister*) eggs was determined in the laboratory since this information was lacking in the literature. Tests were conducted at 5, 10, 15, and 20 C. Treatments at 5 and 10 C produced only slight effects. The low level of mortality among the eggs at 5 C represented a combination of natural mortality and mortality from the experimental method. An increase in mortality occurred at 10 C; but the most significant increase in mortality occurred at 15 and 20 C.

This study demonstrated a significant increase in egg mortality at temperatures as low as 15 C. Interpolation between the mortality curve at 10 and 15 C would suggest an incipient lethal temperature of about 12 C.

Reproductive success at various elevated temperatures could be computed from the egg thermal tolerance and the fecundity rate of the 25 females sampled in this study. The behavioral response of "berried" females may be an important factor, however, in preventing egg thermal mortality. The catch of female crabs was highest during the winter and spring. Thus, an onshore movement was indicated during periods of minimum temperatures, which rarely exceeded 9 C. Egg temperature tolerance may be a significant factor in the reproductive success of the Dungeness crab population.

Thermal tolerance tests were conducted on adult Dungeness crabs. Upper lethal temperatures ranged from 25 to 29 C. The seasonal acclimation of poikilotherms to the surrounding environment is a well-known phenomenon. Thermal tolerance experiments were periodically conducted on adult crabs between September 1970 and August 1971 for the purpose of demonstrating dynamic acclimation in this species. Thermal tolerance declined through the winter months, increased during the spring and summer months, and reached a maximum in August-September, following the seasonal patterns in ambient temperature and salinity changes.

The tolerance to upper lethal temperatures for *Cancer gracilis* ranged from 25 to 28 C. A steeper response curve for *C. gracilis* as compared to

C. magister suggested a narrower thermal range but higher tolerance at lower temperatures.

The behavioral response of adult Dungeness crabs was investigated in a thermal gradient tank. Thermal avoidance during the summer experiments was evident from the rare occurrences of crabs staying in temperatures above 15.5 C. During the winter experiments no crabs were recorded in temperatures above 15.1 C. Avoidance behavior at elevated temperatures was most apparent during the winter trials. This response may be due to an increased thermal sensitivity brought about by changes in salinity in the winter environment. The preferred summer and winter temperatures represented nearly equal Δt's above ambient conditions. The difference between average ambient temperatures and the crabs' summer and winter mean preferred temperatures were 1.8 and 1.6 C, respectively.

It seems likely that at low Δt's (2 C) above ambient, crabs would be attracted to warmer regions; however, increase in the Δt above this level would elicit an avoidance response. During winter Δt's of more than 6 C would exclude crabs from an area, and during summer Δt's above 7 C.

10.5.2.3 Fishes

The Pacific snakeblenny (*Lumpenus sagitta*) was found to have the lowest thermal tolerance of any of the species of demersal fish tested. Upper lethal temperatures ranged from 25 to 28 C. Its distribution extends from the Bering Sea to Northern California. Acute lethal temperatures for five species of juvenile flatfishes tested during July and August, 1970 ranged from 25 to 28 C. In order of increasing thermal tolerance they were rock sole (*Lepidopsetta bilineata*), English sole (*Parophrys vetulus*), butter sole (*Isopsetta isolepis*), sand sole (*Psettichthys melanostictus*), and starry flounder (*Platichthys stellatus*). No significant difference was found among the slopes of the curves for all five species, but significant difference was seen in intercept between starry flounder and the other species. The starry flounder is apparently adapted to withstand a higher environmental temperature than the others. Since it is considered a tolerant, wide-ranging species because of the variety of habitats it occupies, the finding of its significantly higher thermal tolerance is consistent with its ecology. Behavior tests on the avoidance response

of starry flounder in a dual thermal gradient trough were inconclusive. The rock sole has the most northerly distribution of the four species of sole. An adaptation of this species to a cooler average climate than the others may contribute to its lower thermal tolerance. Reported geographical ranges for the remaining species tested provide no clue to the source of the differences observed in the tests among them.

10.5.3 Predicted Thermal Effects

Bendiner et al. (1972) reported the following on the tracer dye studies conducted in the area surrounding Kiket Island. The average equilibrium increased temperature produced by an outfall in this system is dependent on the stratification of the water column and on the runoff flowing into the system from the Skagit River. High stratification and plentiful runoff combined during the June 1971 dye study to limit the increase in temperature; in March low runoff and vertical mixing resulted in a greater increase in temperature. Presumably, the temperature distribution in September would more closely resemble that in March. The temperature increases resulting from the injection at the location south of Skagit Island used in these particular experiments were 0.25 C in June and 0.61 C in March. Unless the processes at work were completely misunderstood, it is difficult to see how a release at this location could result in a volume average increase of over 0.8-1.0 C at the worst.

Superimposed on the average temperature increase in Hope Island and Similk Bays is a field of plumes with characteristic scales of 50-1,500 m horizontally and 2-30 m vertically (depending on the stratification) lasting 6 hr or less in duration. This fluctuation seems to be both smaller (spatially) and faster than the natural fluctuations of the ambient temperature. The direct plume prior to mixing was about 10 C above ambient, but a more typical maximum plume temperature was 2-3 C above ambient. The peak temperatures are entirely dependent on the design of the outfall, and almost any desired value can be produced by careful diffuser design. If extremely rapid mixing is achieved in this way, the stratification/flushing mechanism (thought to be partially responsible for the lower overall rise in June) may be circumvented; the desirability of this must be carefully considered. This distribution of plumes would be detectable over the ambient temperature field under most conditions; during some seasons, the typical rise in excess temperature of 2-3 C would be very evident.

Some locations for the outfall can be expected to be better than the one tested in these field dye studies. Studies in the Puget Sound Model at the University of Washington Department of Oceanography have indicated that mid-channel just north of Skagit Island may be a better location, but the flow in the entire area is so highly variable that a "best" location will not guarantee minimal effects at all times. Control of the field of plumes can only be assured by proper diffuser design.

The thermal effects studies on species of fish and invertebrates indicate that the temperatures predicted to result from once-through cooling will not be of ecological significance. However, attention must be given to proper discharge design and location.

11.0 TOXICITY OF CHLORINE AND HEAT TO PINK AND CHINOOK SALMON

by

Q. J. Stober and C. H. Hanson

11.1 INTRODUCTION

The effects of chlorine on aquatic organisms are currently under close scrutiny by pollution control agencies because chlorine is widely used as an antifoulant in thermal power plants. Chlorine is an effective biocide (Dobson, 1946); however, a review of the application rates in only a few plants reveals a wide variance (Zeller and Rulifson, 1970). Chlorine cannot be used indiscriminately because of ecological or economic reasons. The effective application of chlorine as an antifoulant at Kiket Island was investigated in another study (Stober, Hanson, and Swierkowski, 1973). The toxicity of chlorine at increased temperatures to nontarget organisms is the focus of this study.

Several workers have tested the toxicity of chlorine to salmonids in fresh and salt water (McKee and Wolf, 1963; Holland et al., 1964). Most investigations have been over long continuous exposure times, but these are not likely to occur for any single group of fishes because of the random discharge of chlorine, its rapid detoxification in sea water (i.e., due to chlorine demand, u-v radiation, and dilution), and the behavioral response of fishes when exposed to sublethal concentrations (Sprague and Drury, 1969). Little information has appeared, however, on either the synergism of heat and chlorine or the dose response with fluctuating chlorine concentrations in sea water. These were the objects of tests conducted on juvenile pink and chinook salmon.

11.2 MATERIALS AND METHODS

11.2.1 Dynamic Chlorine Experiments

A series of dynamic chlorine experiments were conducted for the purpose of determining the effect of some environmental conditions on the rate of chlorine decay. Chlorine was added to sea water, and the rate of decay was monitored under light and dark conditions. The experimental apparatus consisted of an aquarium, holding a standard volume of 48 liters, immersed in a continuous-flow water bath in which the ambient test temperature was maintained. Stirring motors continuously circulated the test solution. Light was excluded by enclosure of the test apparatus in black (Visqueen) plastic. Chlorine was introduced as aqueous sodium hypochlorite ($NaClO - 5\ H_2O$).

11.2.2 Heat and Chlorine Bioassays

Toxicity tests with heat and chlorine were conducted aboard the R.V. *Kumtuks* while anchored off the northwest shore of Kiket Island. Wild juvenile pink salmon were collected during migration by dipnet in the vicinity of Kiket Island. Juvenile chinook salmon were obtained from the Washington State Department of Fisheries Skagit Hatchery on June 13, 1972. Each group was held in separate holding tanks or floating pens in sea water for an acclimation period of at least 72 hr prior to testing.

The combined effects of heat and chlorine were tested through two procedures: (1) a matrix of five residual chlorine concentrations (0.05, 0.1, 0.25, 0.5, and 1.0 ppm) at four exposure times (7.5, 15, 30, and 60 minutes) and at four temperatures (Δt 0, 2.6, 4.9, and 10.0 C) was tested; (2) equilibrium loss and death times at a residual chlorine concentration of 0.1 ppm were tested at 11.6 (ambient) 13.5, 16.4, and 20.8 C. The heat-chlorine bioassays were conducted in a 26.4-gal plexiglass aquarium. The sea water was continuously recirculated with a submersible pump (Teel Model 1P681) at 10 gpm (37.8 l/min) through 10 inches (25.4 cm) of clean beach gravel and shell placed in the bottom. This measure ensured homogeneous mixing of heated water and toxicant. A 1,000-watt (Precision Scientific Company) stainless steel submersible electric water heater equipped

with a thermostatic control and stirring motor was used to heat the system to a constant temperature.

The system was filled with ambient sea water and the temperature was increased if greater than ambient was to be tested. A calculated volume of concentrated sodium hypochlorite solution (Bakers analyzed reagent) was introduced with a hypodermic syringe until the demand had been exceeded. The residual chlorine concentration and the temperature were monitored at 5-min intervals. Fish were introduced when the desired residual concentration was achieved and had stabilized. Observations of the test conditions were continued at 5-min intervals during fish exposure periods.

Residual chlorine concentrations were quantified with the orthotolidine method (Standard Methods, 1971). Water samples were taken from a depth of 8 inches (20.3 cm) below the surface with a glass siphon. Samples were held in dark amber glass bottles, cleaned, and rinsed with chlorine-demand-free water. Samples were tested with the orthotolidine indicator within 1 min of sampling and held in a darkened water bath at 20 C for 2 to 5 min for complete color development. Colorimetric measurements were made with a Bausch and Lomb spectrophotometer (Spectronic 20) and a Hach Model DR-EL photometer. Residual concentrations were checked periodically with the Spectronic 20.

Water quality was monitored during all tests. Salinity was measured with a Goldberg refractometer, pH with a Scientific Model 21 meter, dissolved oxygen by the modified Winkler titration, and temperature with a resistance type thermometer.

Test fish were transferred to 34.3 cm x 19.7 cm x 26.7 cm (13-1/2 inch x 7-3/4 inch x 10-1/2 inch) floating cages constructed of 0.14-inch (3.5 mm) mesh vexar attached to wood frames. To allow recovery from any handling effects all fish were held a minimum of 3 hr in a holding tank with ambient sea water. Ten individuals were held in each cage. A control group was tested at each particular excess temperature before the addition of chlorine. Four cages with fish were transferred simultaneously to the test aquarium once the desired residual chlorine concentration and temperature had been established. Each cage was then removed at successive intervals of exposure (7.5, 15, 30, and 60 min) and transferred to a holding tank with continuous-flowing ambient sea water and maintained under observation for 24 hr. Time

to loss of equilibrium and death was observed during the stress and recovery periods. After each test the aquarium system was drained, scrubbed, and washed with a weak solution of sodium thiosulphate. The vexar cages were scrubbed and rinsed in running sea water for 1 to 2 hr.

Fish mortality was established as a cessation of opercular movement upon stimulation with a small probe. Loss of equilibrium (EL) was defined as the initial time when abnormal behavior was exhibited prior to death (usually the belly-up position). The exact time of initial abnormal behavior was sometimes difficult to determine and became subjective because some fish although affected would appear normal until death. Mortalities were removed as they occurred.

Using the same system and procedure, we exposed juvenile chinook salmon to a residual chlorine concentration of 0.1 ppm at the four sublethal temperatures. Twenty-five individuals were tested at each temperature. The time to loss of equilibrium and death was observed for comparison with thermal tolerance data obtained for this species in the previous 2 yr.

11.2.3 Experiments with Fluctuating Concentrations

Five 15-gal (56.8 l) continuous-flow bioassay aquaria were used in these experiments. Ambient sea water was supplied from a constant-head tank through a distribution manifold. The flow to each aquarium was regulated by restriction valves to 0.5 l/min. The test aquaria were partially submerged in a continuous-flow sea water bath so that ambient temperature was maintained. A solution of sodium hypochlorite was introduced into the influent water supply with a Sage proportionating or syringe pump in order to achieve the desired concentration prior to discharge into the aquaria. Four aquaria were treated with maximum concentrations ranging from 0.05 to 1.0 ppm chlorine during a 2-hr exposure period; the remaining aquarium was used as the control. All fish tested were experimentally naive, and the survivors were released.

Before testing aquaria were scrubbed with a weak sodium thiosulphate solution and rinsed 4 to 6 hr in running sea water. Test individuals in groups of 15 to 25 were placed in each aquarium and allowed a 3-hr minimum acclimation period prior to the introduction of chlorine. Residual chlorine was sampled in each aquarium and analyzed as described above.

PVC plastic, rubber, and glass were used throughout the systems.

Observations of the test organisms were made continuously during the 2-hr exposure to chlorine, then at routine intervals for the succeeding 24 hr.

11.3 RESULTS

11.3.1 Chlorine Dynamics

A series of experiments to describe the rate of chlorine decay under various conditions were conducted for determination of its effective use as a fouling control agent. The amount of chlorine (sodium or calcium hypochlorite) solution needed to achieve any given residual chlorine concentration depends on the dilution of the toxicant and the chlorine demand of the water. Chlorine demand can be defined as the amount of chlorine, free or combined, that will be removed or destroyed by reaction with constituents of the water. The decay reaction rate of a particular solution is dependent on pH, ammonium ion (which combines with chlorine to form chloroamine), and certain reducing agents. Inorganic reducing agents present in sea water include sulfur, iron, and manganese. Organic substances also contribute to chlorine decay rates. Temperature has a considerable influence on the reaction rate. The rate of chlorine decomposition to released oxygen is dependent on light intensity, as this reaction is catalyzed by ultraviolet light. Graphic representation of the effects of light on the rate of chlorine decay in sea water are presented in Fig. 11-1. The slope of the regression line indicates the relative rate of chlorine decay in each test situation.

The results indicate the time required to reduce a chlorine concentration from a defouling value of 1.0 ppm to .01 ppm, a level where intermittent exposure to fish would not be likely to cause distress. Light reduced the required time to decay (1.0-0.005) by a factor of almost 7. The sea water temperature averaged 13.5 C $\pm$ 1.2 C and the pH, 7.44 $\pm$ 0.03 during tests with ambient light and 13.3 C $\pm$ 1.3 C and pH 7.90 $\pm$ 0.04 during the decay rate tests under dark conditions. Salinity and turbidity averaged 22 ppt and 4.4 JTU, respectively, in the lighted test and 27 ppt and 3.1 JTU, respectively, in the dark tests.

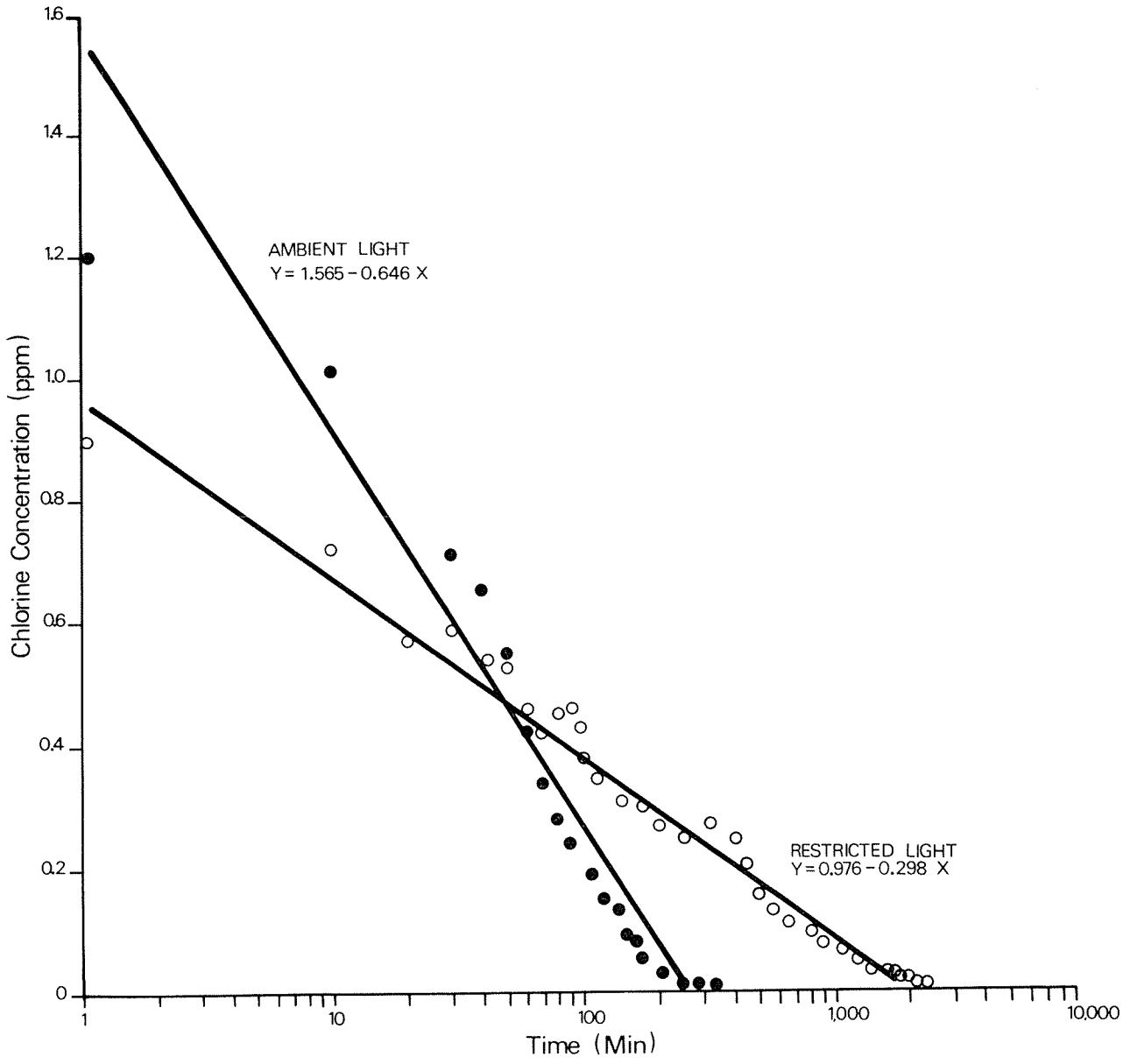

Fig. 11-1. Least square regression of the effect of ambient light on the rate of residual chlorine decay.

11.3.2 Heat and Chlorine Bioassays with Chinook Salmon

A total of 1,519 juvenile chinook salmon (mean standard length of 171 = 67.7 mm, S.D. = 10.8) were tested between June 17 and 26, 1972. A complete matrix of five residual chlorine concentrations (0.05, 0.1, 0.25, 0.5, and 1.0) was tested at four temperatures beginning at mean ambient temperature and at average increased temperatures of 2.6, 4.9, and 10 C above ambient. The temperatures were sublethal during the exposure times tested. The order of tests was randomized so that environmental influences during the test period would not be confounded. Each matrix was then stressed at four exposure periods lasting for 7.5, 15, 30, and 60 min, which were selected so that cooling water travel time or exposure in a transient thermal plume would be simulated. A probit analysis of the observed dose-response of each bioassay was conducted. The median lethal times (LT-50) obtained under the combined doses of residual chlorine and increased temperatures are presented by exposure period tested in Fig. 11-2. A biological response (mortality) was not observed in all cases tested. Some tests were replicated, as indicated by dual sets of observations, and the mean was plotted. All curves were fitted by eye.

The test with the 7.5-min exposure period (Fig. 11-2) demonstrated that the lethal threshold concentration (LC-50) as defined by Sprague (1969) occurred at a residual chlorine concentration of 0.5 ppm at an average ambient temperature of 11.7 C. Average increased temperatures of 2.6, 4.9, and 10 C above ambient reduced the LC-50 to 0.25, 0.1, and 0.1 ppm chlorine, respectively. Since these curves are asymptotic with both axes, the minimum time in which lethal action occurred was reduced by approximately an order of magnitude with an increase of 10 C at 0.5 ppm residual chlorine. The minimum time for lethal action occurred at about 37 min at 0.5 ppm residual chlorine with a Δt of 10 C. All mortality occurred after the exposures while fish were "recovering" in ambient sea water.

With the 15-min exposure period (Fig. 11-2), LC-50 occurred at 0.5 ppm residual chlorine at a mean ambient temperature of 11.7 C. The LC-50 at average excess temperatures of 2.6, 4.9, and 10 C was 0.1 ppm residual chlorine. An approximate order of magnitude of decrease in the time in which lethal action occurred was apparent with an increase of 10 C at 0.5 ppm.

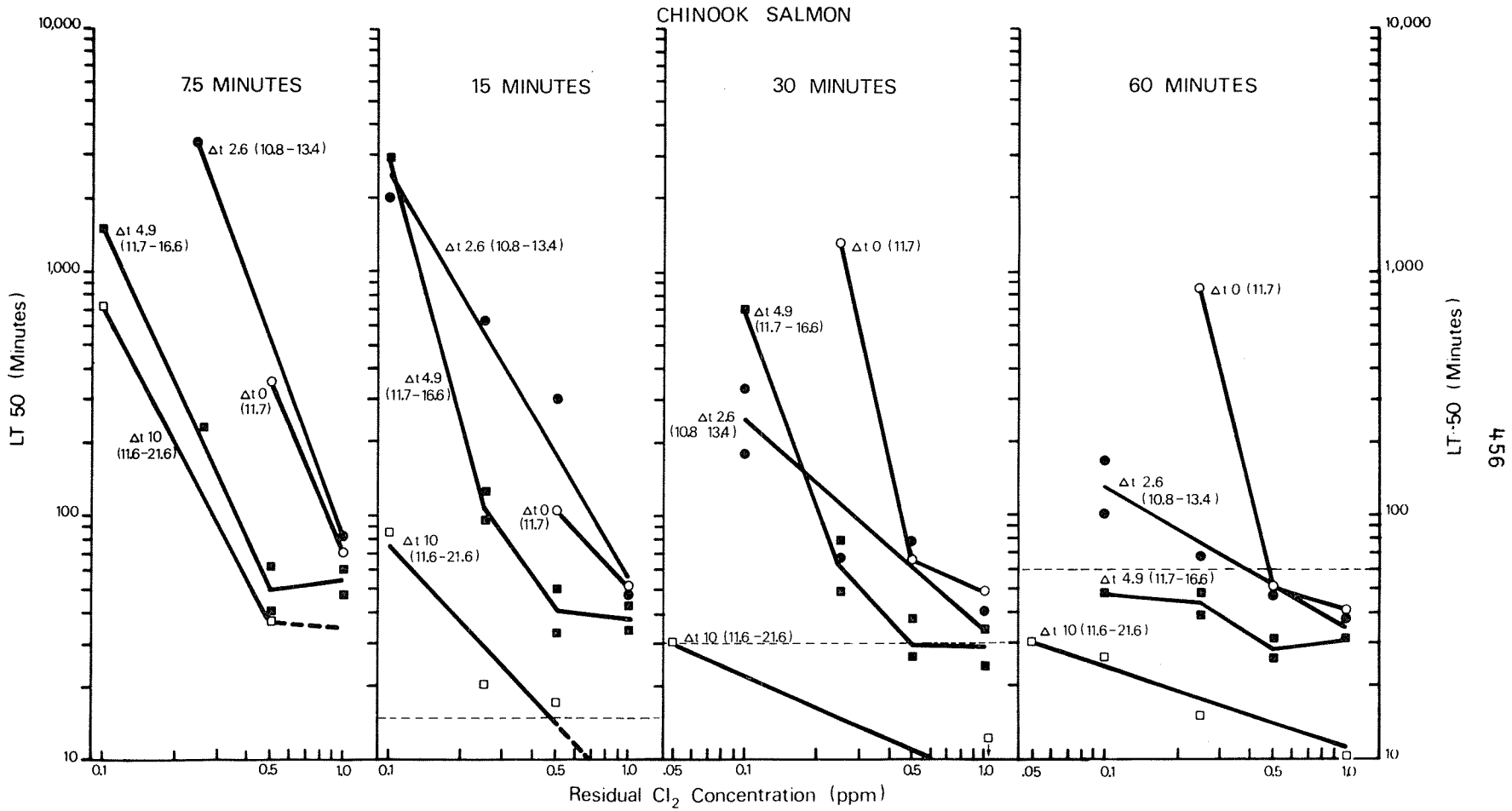

Fig. 11-2. Median lethal times (LT-50) calculated by probit analysis of tests conducted at various esposure times, residual chlorine concentrations, and increased temperatures (Δt) for chinook salmon.

An overall reduction in the LT-50 was evident due to the doubling of the stress time. Rapid mortality was evident within the 15-min exposure period at concentrations above 0.5 ppm chlorine at a Δt of 10 C.

With the 30-min exposure period (Fig. 11-2), the lethal threshold concentration (LC-50) occurred at 0.25 ppm residual chlorine at an average ambient temperature of 11.7 C. A reduction of 50 per cent occurred in the LC-50 observed at the 7.5 and 15-min stress periods. The LC-50 at mean excess temperatures of 2.6 and 4.9 C was 0.1 ppm residual chlorine; however, at an excess temperature of 10 C, the LC-50 was reduced to 0.05 ppm. An approximate order of magnitude of decrease in the time in which lethal action occurred was again evident with an increase of 10 C at 0.5 ppm residual chlorine. Mortality occurred rapidly during the 30-min stress period at 0.05 ppm, and greater at 10 C above ambient.

The 60-min exposure period (Fig. 11-2) was the most acutely toxic to chinook salmon. The lethal threshold concentration (LC-50) occurred at 0.25 ppm residual chlorine at mean ambient temperature of 11.7 C. The LC-50 at mean excess temperatures of 2.6 and 4.9 C was 0.1 ppm, while that at 10 C above ambient was 0.05 ppm residual chlorine. Nearly all mortality occurred within the 60-min stress period. The LT-50 at the 30- and 60-min stress periods were essentially equal, indicating that the method of testing was consistent and that mortality was essentially complete after 30 min of exposure at an excess temperature of 10 C.

During the testing, the salinity averaged 24.9 ppt and ranged from 20 to 28 ppt; the pH averaged 7.77 and ranged from 7.66 to 7.83; and the dissolved oxygen concentrations averaged 9.4 ppm.

The median time to loss of equilibrium (ELT-50) was calculated on the equilibrium loss response prior to death. The ELT-50 was calculated to precede the LT-50 by an average 55 per cent over 61 paired tests. Thus, in order to avoid obvious behavioral changes in juvenile chinook salmon, one should reduce the values plotted in Fig. 11-2 by at least 55 per cent of the response (LT-50) times shown, if one expects exposures at these chlorine concentrations and excess temperatures.

The time to loss of equilibrium and death was observed at a residual concentration of 0.1 ppm chlorine at four sublethal test temperatures. A total of 205 chinook salmon (mean standard length = 78.0 mm, S.D. = 10.5)

was tested between June 27 and 29, 1972, at 11.6 (ambient), 13.5, 16.4, and 20.8 C temperatures. The geometric mean times to equilibrium loss (EL) and death (D) with the 95-per cent confidence intervals at each test temperature are plotted in Fig. 11-3. Regression equations for the resistance times to EL and death were calculated. The slopes were not significantly different, indicating that the lines were parallel. The EL response again preceded the time to death by about 55 per cent; it would appear that the EL time is a biological response of importance in the establishment of design criteria and is a biologically meaningful safety factor. The resistances to upper lethal temperatures alone developed in 1971 chinook salmon thermal resistance tests are presented for comparison. Salinity averaged 23.6 ppt and ranged from 20.5 to 27.0. Dissolved oxygen was 9.1 ppm and ranged from 8.1 to 11.7 ppm.

A summary of the lethal threshold chlorine concentrations (LC-50 in ppm residual chlorine) for juvenile chinook salmon at the test temperatures and exposure periods is presented in Table 11-1.

Table 11-1. Summary of the lethal threshold residual chlorine concentrations (ppm) for juvenile chinook salmon at temperatures and exposure periods tested

Test temperature	Exposure period (min)			
	7.5	15	30	60
	ppm residual chlorine			
Ambient (11.7 C)	0.5	0.5	0.25	0.25
Δt 2.6 C	0.25	0.1	0.1	0.1
Δt 4.9 C	0.1	0.1	0.1	0.1
Δt 10 C	0.1	0.1	0.05	0.05

The lethal threshold concentrations (LC-50) for juvenile chinook salmon decreased both with increased exposure time and temperature.

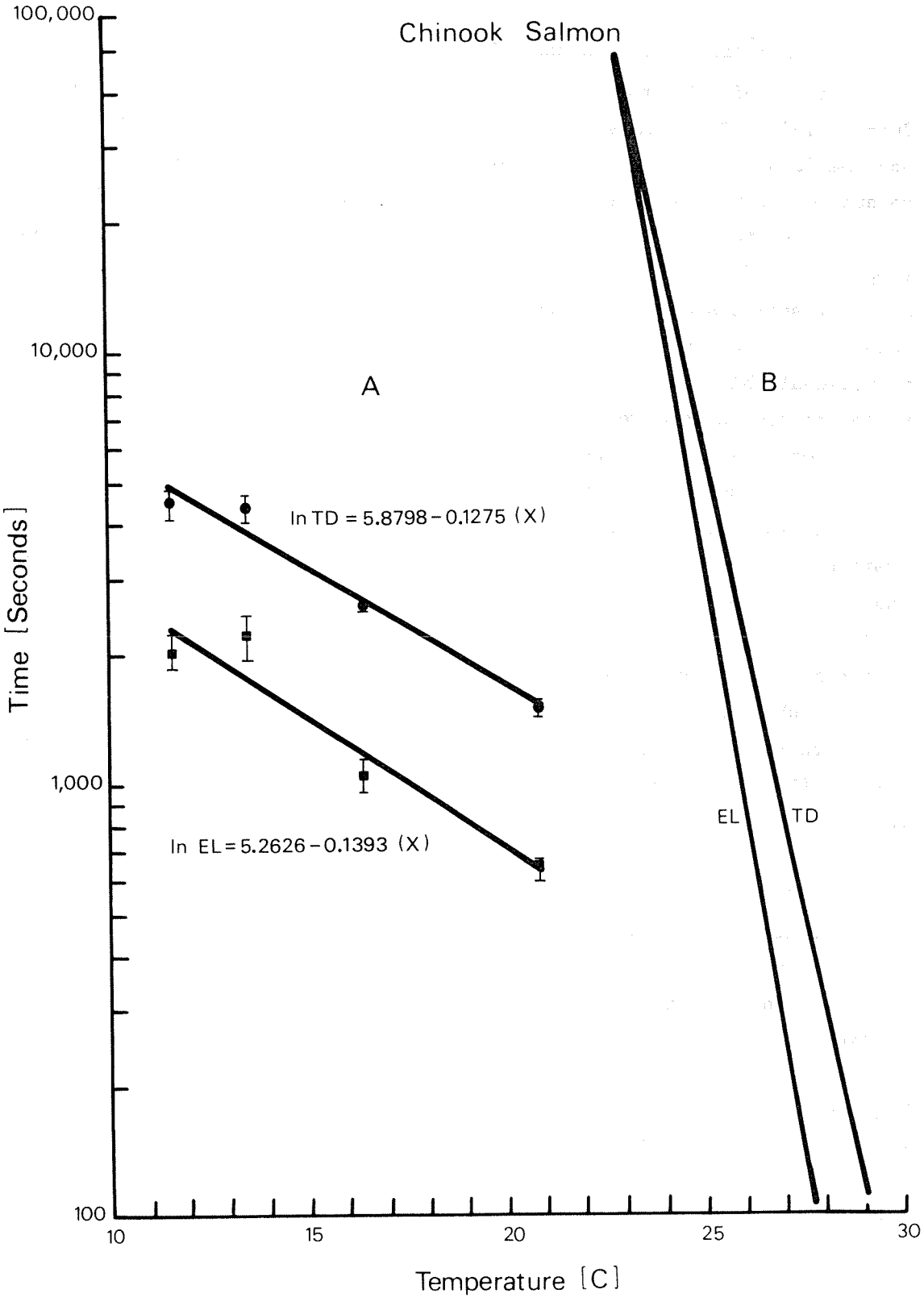

Fig. 11-3. The geometric mean times to equilibrium loss and death at 0.1 ppm residual chlorine (A) with 95% confidence intervals at each test temperature are compared with similarly determined resistance times to upper lethal temperatures (B) for chinook salmon in 1971.

11.3.3 Heat and Chlorine Bioassays with Pink Salmon

A total of 967 juvenile pink salmon was tested between May 27 and June 5, 1972. The mean standard length of a sample of 100 pink salmon was 35.6 mm (S.D. = 6.1). A partial matrix of heat-chlorine bioassays was conducted. Five residual chlorine concentrations ranging from 0.05 to 1.0 ppm were tested at mean ambient temperature (13.6 C), and at mean excess temperatures of 5.0 and 9.9 C at exposure periods of 7.5, 15, 30, and 60 min. A probit analysis of the observed dose-response of each bioassay was conducted. The median lethal times (LT-50) obtained under the combined doses of residual chlorine and excess temperatures are presented by exposure period tested and plotted in Fig. 11-4. A biological response (mortality) was not observed at 0.05 ppm chlorine; however, it was not tested at the 5 and 9.9 C excess temperatures. All lines were fitted by eye.

With the 7.5-min exposure period (Fig. 11-4), lethal threshold concentration (LC-50) occurred at a residual chlorine concentration of 0.05 ppm and at an average ambient temperature of 13.6 C and excess temperatures of 5 and 9.9 C. The minimum time in which lethal action occurred was about 43 min at 1.0 ppm residual chlorine. All mortality occurred after the exposures, while fish were "recovering" in ambient sea water.

With the 15-min exposure period (Fig. 11-4) the lethal threshold concentration (LC-50) occurred at 0.25 ppm residual chlorine at a mean ambient temperature of 13.6 C. However, a reduction in the LC-50 was evident due to the doubling of the stress time. The LC-50 at excess temperatures of 5 and 9.9 C were 0.5 and 0.1 ppm, respectively. There was an apparent 60 per cent reduction in the time in which lethal action occurred with an increase in temperature of 9.9 C at 0.5 ppm residual chlorine.

With the 30-min exposure period (Fig. 11-4), lethal threshold concentration (LC-50) occurred at 0.25 ppm residual chlorine at an ambient temperature of 13.6 C. The LC-50 at excess temperatures of 5 and 9.9 C was 0.1 ppm residual chlorine. An approximate reduction of about 50 per cent occurred in the time in which lethal action occurred with a Δt of 9.9 C at 0.5 ppm. Mortality occurred rapidly during the 30-min stress period especially with a 9.9 C Δt.

The 60-min exposure period (Fig. 11-4) was the most acutely toxic to pink salmon. The lethal threshold concentration occurred at 0.25 ppm residual chlorine at ambient temperature (13.6 C). The LC-50 at excess temperatures of 5 and 9.9 C were 0.1 ppm, the lowest concentration tested. Nearly all mortality occurred within the 60-min stress period.

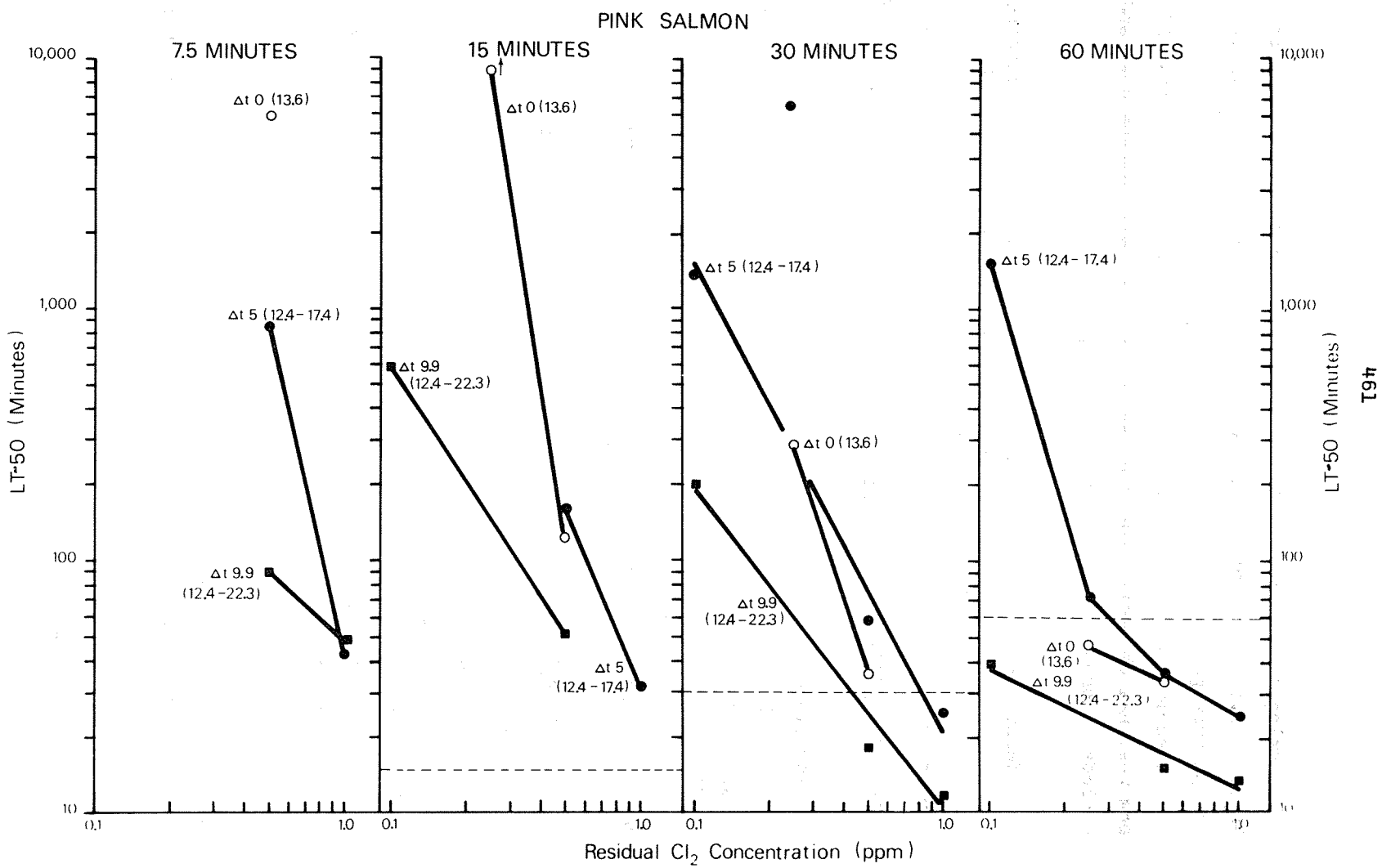

Fig. 11-4. Median lethal times (LT-50) calculated by probit analysis of tests conducted at various exposure times, residual chlorine concentrations, and increased temperatures (Δt) for pink salmon.

During these tests, salinity averaged 23.5 ppt and ranged from 20 to 26 ppt. Dissolved oxygen averaged 9.4 ppm and ranged from 7.2 to 10.7 ppm. The pH averaged 7.53 and ranged from 7.23 to 7.80.

A summary of the lethal threshold chlorine concentrations (LC-50 in ppm residual chlorine) for pink salmon at the test temperatures and exposure periods is presented in Table 11-2.

Table 11-2. Summary of the lethal threshold residual chlorine concentrations (ppm) for juvenile pink salmon at temperatures and exposure periods tested

Test temperature	Exposure period (min)			
	7.5	15	30	60
	ppm residual chlorine			
Ambient (13.6 C)	0.5	0.25	0.25	0.25
Δt 5.0 C	0.5	0.5	0.1	0.1
Δt 9.9 C	0.5	0.1	0.1	0.1

The lethal threshold concentrations (LC-50) for juvenile pink salmon decreased both with increased exposure time and temperature.

11.3.4 Experiments with Fluctuating Concentrations

A total of 855 juvenile pink salmon was tested between May 2 and 21, 1972, in 37 continuous-flow bioassays in which chlorine was introduced at various residual concentrations with maxima ranging from 0.01 to 1.0 ppm during 2-hr exposure periods. The idealized dose rate exposure curves fit by the method of polynomial least squares are presented in Fig. 11-5. Mean chlorine concentrations were calculated from individual dose-rate curves for each continuous-flow bioassay and plotted against the LT-50 calculated by probit analysis (Fig. 11-6). The curve indicated lethal threshold concentration occurred at an average 0.045 ppm residual chlorine. The minimum time for lethal action occurred in about 100 min at about 0.5 ppm residual chlorine.

The ambient temperature averaged 10.1 C and ranged from 8.0 to 13.7 C. The salinity averaged 26.7 ppt and ranged from 23 to 30 ppt. Dissolved oxygen averaged 9.7 ppm, and pH averaged 7.57 and ranged from 7.31 to 7.86.

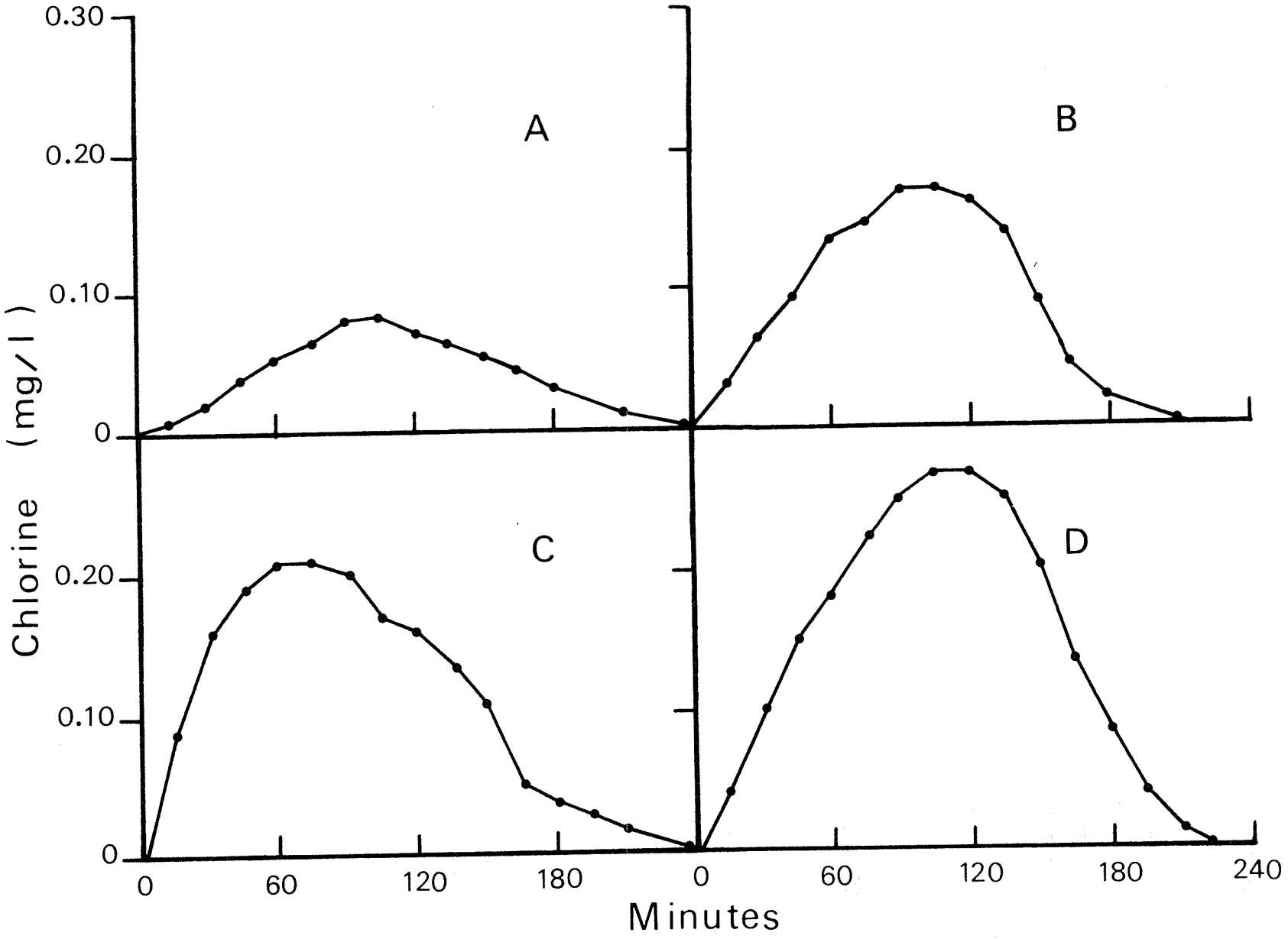

Fig. 11-5. Polynomial least-square estimates of the residual chlorine concentrations (increasing A-D) applied during 2-hr dose periods in continuous flow bioassay tanks.

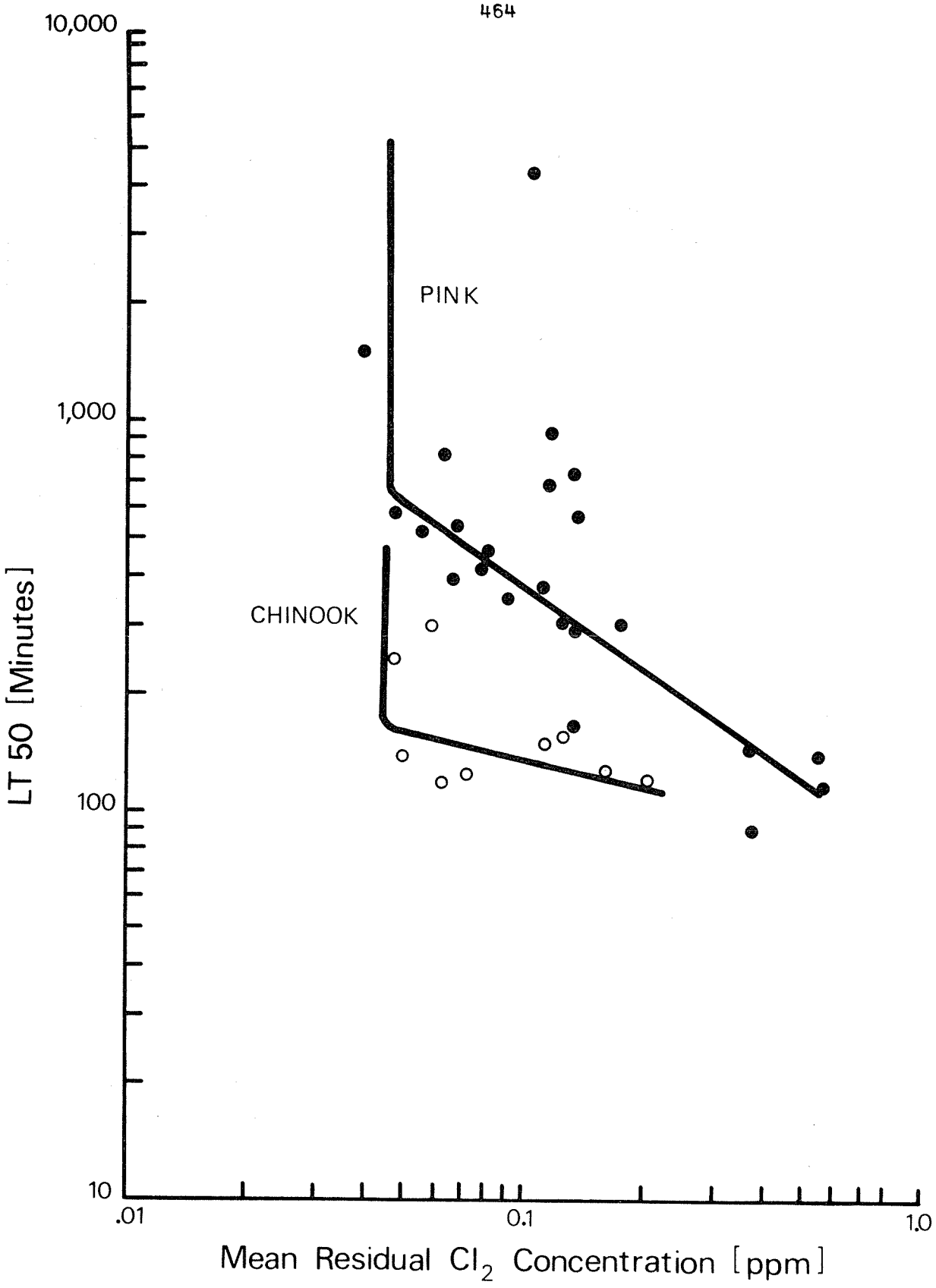

Fig. 11-6. Median lethal times (LT-50) calculated by probit analysis of bioassays conducted with fluctuating residual concentrations of chlorine (means are plotted) for pink and chinook salmon.

A total of 283 juvenile chinook salmon was tested between June 23 and 30, 1972, in 12 continuous-flow bioassays in which chlorine was introduced at maximum residual concentrations ranging from 0.005 to 0.38 ppm during 2-hr exposure periods as described above (Fig. 11-6). The curve indicated lethal threshold concentration occurred at an average 0.045 ppm. Chinook salmon appeared to have a more rapid response than pink salmon; however, the LC-50 was equal for both. The greater sensitivity of chinook salmon may have resulted from a change in water quality which occurred during the time the chinook salmon were tested. The ambient temperature averaged 11.5 C. Salinity averaged 18.5 ppt and ranged from 14 to 22 ppt; pH averaged 7.76 and ranged from 7.35 to 8.14. Dissolved oxygen averaged 11.6 ppm. A general temperature increase, reduction in salinity, and increase in pH may have been responsible for the greater sensitivity indicated for chinook salmon than for pink salmon.

11.4 SUMMARY AND CONCLUSIONS

The findings are summarized below.

1) Light reduced the decay time of residual chlorine from 1.0 to .005 ppm by approximately a factor of seven. The decay rate from 1.0 to 0.01 ppm, during which residual chlorine is reduced from an effective antifoulant, to one not likely to cause distress to fish when discharged intermittently, is given.

2) Juvenile chinook salmon were tested in a matrix design incorporating five residual chlorine concentrations (0.05, 0.1, 0.25, 0.5, and 1.0 ppm), at four temperatures (Δt, 0, 2.6, 4.9, and 10 C). Each matrix was stressed at four exposure periods (7.5, 15, 30, and 60 min).

3) The median time to loss of equilibrium (ELT-50) for juvenile chinook salmon was calculated to precede the time to death (LT-50) by an average of 55 per cent. The ELT-50 and LT-50 for chinook exposed to 0.1 ppm residual chlorine at test temperatures of 11.6 (ambient), 13.5, 16.4, and 20.8 C were determined. Regression of the geometric mean times to equilibrium loss again preceded the time to death by about 55 per cent. The biological implications of equilibrium loss are discussed for chinook salmon.

4) Juvenile pink salmon were tested in a matrix design incorporating five residual chlorine concentrations (0.05, 0.1, 0.25, 0.5, and 1.0 ppm) at three temperatures (ambient 13.6 C, Δt 5.0, and 9.9 C). Each matrix was stressed at four exposure periods (7.5, 15, 30, and 60 min).

5) The minimum time for lethal action for both pinks and chinooks occurred in all tests at an excess temperature of 10 C.

6) Mortality occurred, both during exposure to chlorine and "recovery" in ambient sea water.

7) Median lethal times for pink and chinook salmon exposed to fluctuating chlorine concentrations during a 2-hr exposure period are compared. The lethal threshold concentration was 0.045 ppm residual chlorine for both species. Chinook salmon appeared to have a more rapid response than pink salmon, even though the lethal thresholds for the two species were equal.

8) Water quality (temperature, pH, salinity, and dissolved oxygen) is presented for each test situation.

If chlorine treatment is to be used to control marine fouling within a power plant cooling system, the possible detrimental effects on nontarget aquatic life must be considered. The residual chlorine used to control fouling can be substantially reduced or eliminated before discharge into the receiving waters through proper design of the cooling system with due application of the dynamics of chlorine decay. The effects of dilution and mixing and realistic decay rates for chlorine residuals within the cooling system and dechlorination techniques by the use of sulfur dioxide should be considered so that the impact of cooling system chlorination on nontarget organisms can be minimized or eliminated.

An avoidance response by fish to chlorine encountered in discharge plumes has been reported by White (1972). Sprague and Drury (1969) reported a similar avoidance behavior for juvenile salmonids exposed at residual chlorine concentrations of 0.01 and 1.0 ppm. However, a preference response was observed at a chlorine concentration of 0.1 ppm, which must be considered if chlorine discharge at this concentration is anticipated.

Recommended criteria for the maximum concentration of residual chlorine acceptable for discharge into natural receiving waters have been established by the National Environmental Protection Agency. At the present time the recommended residual chlorine concentration for continuous discharge is 0.002 ppm, that for intermittent discharge is 0.05 ppm for a 2-hr period, and 0.1 ppm for a 30-min period. After discharge, residual concentrations of this magnitude would be rapidly dissipated by the dilution and chlorine demand of the receiving waters.

Continuous chlorination at a residual level of 0.5 ppm has been recommended for fouling control in marine waters (Draley, 1972; Holmes, 1970; White, 1972; and Beauchamp, 1966). The majority of power stations in Britain implement this procedure eight months per year, with slight variations depending on individual plant requirements. In all cases the natural chlorine demand reduced the residual concentrations to 0.1 - 0.05 ppm before discharge (Beauchamp, 1966).

The effect of elevated temperature in a discharge plume where chlorine will be encountered must be considered. Predicted temperature and discharge plume dynamics from a point of discharge were made by the Applied Physics Laboratory, University of Washington (1971). Their results showed a thermal plume from a point discharge would create a temperature increase of 2 - 3 C in the plume field, 50 - 1,500 m horizontally and 2 - 30 m vertically, with a 6-hr maximum duration. This could be reduced, however, with a discharge diffuser.

The toxicology of heat and chlorine must be examined in perspective with the conditions mentioned. Through proper design and implementation, chlorine can be effectively utilized to control marine fouling within a once-through cooling system and yet have minimal impact on non-target organisms inhabiting the discharge-receiving waters.

12.0 SUBTIDAL AND INTERTIDAL MARINE FOULING ON ARTIFICIAL SUBSTRATA

by

C. H. Hanson

12.1 INTRODUCTION

The species composition and seasonal abundance of marine fouling organisms are important considerations in the design and maintenance of a once-through marine cooling system. The objectives of this study were to provide information on the extent and nature of the fouling community and to characterize its seasonal and vertical distribution. The fouling resistances of several substrata commonly used in the construction of power plant cooling systems were used as a basis for characterizing and comparing the development of the fouling community in the subtidal and intertidal.

Colonization by marine fouling organisms in the vicinity of Kiket Island has been examined in the subtidal since April 1972 and in the intertidal since Spring 1971. Long-term and short-term exposures of test surfaces during these time intervals provided information on the rate of organic production, progressive community change, and periods of maximum larval settlement.

This research identifies the potential problems of biofouling on intake structures located at various subtidal levels, and defines the time interval during which antifouling procedures must be considered.

12.2 MATERIALS AND METHODS

12.2.1 Subtidal Fouling

Regional variations in subtidal fouling were examined at test sites established offshore from Kiket and Skagit Islands (Fig. 12-1) at a depth of 18 m below mean sea level. The test devices consisted of panels of six substrata, including copper-nickel alloy, steel, plexiglass, white pine wood, concrete, and anthracite. All media, except anthracite, were cut into squares 10 x 10 cm as this size was small enough for convenient handling and yet produced reliable counts. Three replicates of the steel, plexiglass, and wood were simultaneously exposed in each panel. The panels were arrayed as shown in Fig. 12-2. The arrays were held vertically in the water column by a steel float moored below extreme low water. The location of each array was marked at the surface

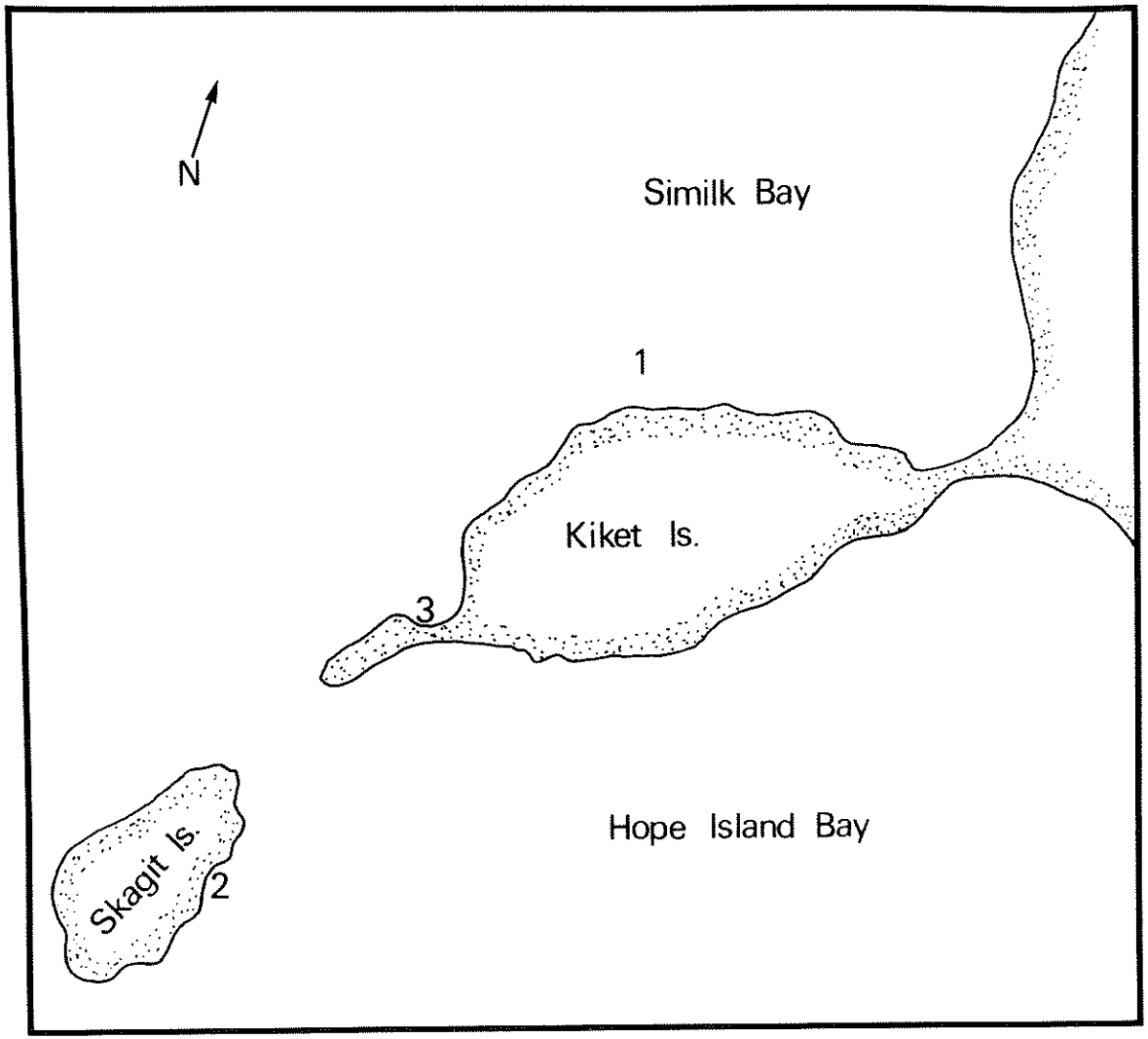

Fig. 12-1. Map of the Kiket Island vicinity: 1) location of Kiket Island subtidal fouling study; 2) location of Skagit Island subtidal fouling study; 3) location of intertidal study.

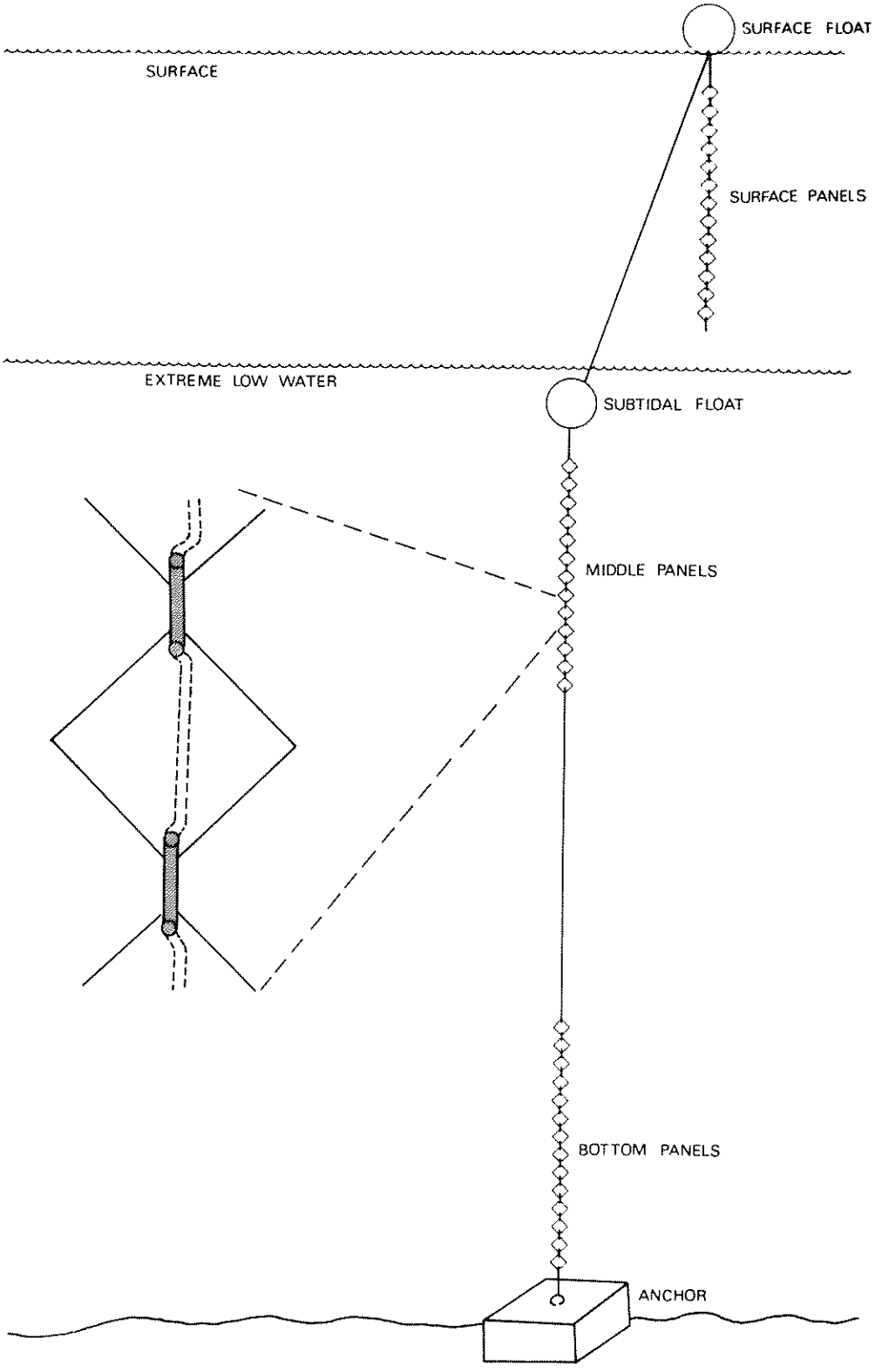

Fig. 12-2. A schematic of the array of subtidal test panels used to measure biofouling with inset showing details of fouling plate attachment.

by a second float. Polypropylene line with a diameter of 3/8 inch was used for mooring. Each array was anchored by a 50- to 80-lb concrete or steel block.

Test panels were suspended at mean depths of 6.1 and 15.3 m below mean sea level, and an additional panel was suspended from the marker buoy at a mean depth of 1 m below the surface. Attachment of the fouling plates was accomplished by "threading" the polypropylene line through 1/2-inch holes drilled in opposite corners of the test plates. The concrete was attached by a 3-inch stainless steel bolt imbedded in the back side of the molded concrete. A wooden backplate and nut clamped the concrete plate to the mooring line. Anthracite was attached to the mooring line by plastic-coated wire. Fouling accumulations on the anchors, line, and floats were also examined.

Fouling plates were exposed for either a short-term (series I) or a long-term (series II). Short-term (series I) panels were exposed for periods of 41 and 79 days in Hope Island Bay and 58 and 101 days in Similk Bay. Long-term (series II) panels were exposed continuously for a period of eight months (April 16 - November 29, 1972) at both locations. This system of exposure provided quantitative and qualitative information on changes in fouling community structure, species dominance, and seasonal distribution pattern.

The standard analytical procedure for recovered series I plates included identification of organisms, estimation of per cent coverage, and measurement of size, where applicable. The organisms from a 7-cm^2 area were scraped onto a preweighed Whatman filter paper, dried at approximately 100 C for 24 hr, and then weighed on a Mettler analytical balance (model H6T Digital). Qualitative monthly observations on environmental conditions and seasonal changes in community structure on the series II plates were made directly with the use of SCUBA.

12.2.2 Intertidal Fouling

The setting rate and colonization by intertidal species were determined by means of artificial test surfaces. Concrete test slabs were constructed, each measuring 38 cm wide by 76 cm long by approximately 15 cm deep. Three-eights-inch-diameter steel reinforcing bars were imbedded in the concrete to insure structural integrity and provide anchorage in the beach.

The slabs were uniform in texture, composition, surface configuration, stability, and resistance to wave action. The test slabs were placed on the beach with the long dimension parallel to the water and the top surface in a horizontal position at the +2, 0, -2, and -4 ft levels relative to mean sea level. A datum line, established in 1969 by Seattle City Light, was used as the major reference. Once each month from December 1971 to September 1972, the existing macrofauna was scraped from a 7-cm^2 area on each test surface. Species present, abundance, and size were determined monthly for each plot.

12.2.3 Terminology

Terms used in the description of the various fouling species include (1) "dominant," which refers to those forms that were outstanding in abundance or influence or, once established, were present throughout the study period; (2) "subdominant," which refers to those forms that were lower in abundance and seasonal in occurrence; and (3) "influent" which refers to all other forms not predominant in terms of biomass (classification scheme modified from DePalma, 1966).

12.3 RESULTS AND DISCUSSION

Qualitative observations were periodically made on the water quality and natural fouling abundance at the Kiket and Skagit Island sites. Water quality varied between the two locations in that turbidity and sedimentation were consistently higher at the Kiket location. The bottom in the vicinity of the fouling plates at Kiket consisted of soft silt and sediment with a few rock outcroppings. At 18 m, light penetration was extremely low, and bottom currents appeared to be generally slow. In contrast, the bottom at Skagit was virtually free of silt and predominantly covered with cobble and bedrock outcroppings. The cobble and rock observed in the Skagit Island vicinity were densely covered with acorn barnacles, *Balanus crenatus*. At 18 m, light penetration was moderate, and bottom currents were consistently more rapid than those observed in the Kiket Island site. Water quality measurements are discussed in Section 4.0.

12.3.1 Subtidal Fouling

12.3.1.1 Species Composition of Organisms by Depth

Five major groups of fouling organisms colonized the artificial substrata during the study period. The most significant groups included barnacles (three species), diatoms, and mussels. Among the less dominant forms were green algae and motile crustacea (copepods and amphipods). A summary of the forms found at each depth is presented in Table 12-1.

Dominating the near-surface layer were colonial diatoms of the genera *Melosira, Navicula,* and *Fragilaria.* The common bay mussel, *Mytilus edulis*, was found exclusively at the surface level. Abundant organisms included three species of acorn barnacle, *B. crenatus, B. glandula,* and *B. cariosus*, and several genera of green algae, *Ulotrix, Ulva,* and *Cladophora.* Many small invertebrate crustacea, including calanoids, harpacticoids, copepods, cladocerans, and amphipods, were observed associated with the diatoms and algae attached to the fouling plates.

At the middle depth, approximately 6.1 m, the species composition of the fouling organisms changed slightly. Green algae became rare and diatoms less dense, although not substantially. *M. edulis, B. glandula, and B. cariosus* were absent. *B. crenatus* increased in density with respect to depth at the Skagit Island location, but not at the Kiket Island site.

With respect to depth, the greatest change in species composition occurred at the bottom level (approximately 15.3 m). Here, the plates were void of the algae, diatoms, and invertebrate crustacea found at the upper levels, but *B. crenatus* was dominant. As noted earlier, consistently higher densities of barnacles were observed at the Skagit location than at the Kiket location. The ratio of barnacle density between the two locations varied as much as 50 to 1 on the wood and concrete media exposed at the bottom level.

The species compositions at the Kiket and Skagit sites were very similar, but the relative abundances of certain fouling species differed. No conclusive explanation can be presented for the differences observed between the two locations. However, the higher turbidity at the Kiket site may have had a marked influence on the rate and degree of successful colonization by sensitive species; it may account for the sharper decrease observed in abundance of green algae with depth at this site. Other environmental variables may

Table 12-1. A summary of the subtidal fouling organisms found on artificial substrata at three depths, and their relative abundance

Depth	Observation date / Exposure period (days)	May 26 / 41	June 12 / 58	July 3 / 79	July 25 / 101
Surface	Dominants	Diatoms	Diatoms	Diatoms *Balanus*	Diatoms *Balanus* *Mytilus*
	Subdominants	Algae	*Balanus* Algae	Algae	
	Influents	Copepods Amphipods	Copepods Amphipods	Copepods Amphipods	Algae
Middle	Dominants	Diatoms	*Balanus*	*Balanus*	*Balanus*
	Subdominants	Algae	Diatoms		
	Influents	Copepods Amphipods		Diatoms	
Bottom	Dominants			*Balanus*	*Balanus*
	Subdominants				
	Influents				

have contributed to the differential fouling densities observed between the two locations, including current flow, sediment load, and exposure to sunlight.

12.3.1.2 Colonization and Decay of Artificial Substrata

The rate and degree of colonization by fouling organisms and the physical decay of the six artificial substrata tested were observed. Variations in the species composition and degree of fouling attachment existed among the substrata under identical exposure conditions and were therefore dependent on the nature of the substrata and not on environmental variations.

The rate and degree of chemical or physical change that made the substratum acceptable as a fouling medium, the first phase in the colonization sequence (Moore, 1958), differed among the media tested. Biological accumulation was slow on the copper-nickel alloy but rapid and complete on the anthracite. Research has shown that the former maintains its fouling resistance properties for approximately 10 months before becoming acceptable as a fouling medium, whereas the latter has a low fouling resistance (Woods Hole, 1952).

Surface configuration and texture also influenced the rate of colonization. The anthracite and concrete had rough or irregular surfaces, and these provided holdfasts for sessile forms such as mussels and barnacles. More extensive and detailed examinations of the effect of surface configuration on fouling accumulation were reported by Crisp and Barnes (1954).

The differences in resistance to fouling among the media were measured from the dry weights of the material taken during the periodic sampling, along with the abundance of specific species present at all test depths. The data from sampling at the near-surface level are shown in Table 12-2. The results are discussed in detail below.

The plates of copper-nickel alloy, which had a gross composition of 90 per cent copper and 10 per cent nickel, were extremely resistant to fouling and physical decay. After 101 days of exposure, the dry weight of removable material was 0.0039 g/cm^2. The material consisted primarily of diatoms, with incidental deposits from scaling and flaking of the medium surface. No barnacles, mussels, or green algae were observed. The slight diatom buildup indicated, however, that fouling was not completely deterred, only the rate of accumulation was altered.

Table 12-2. Dry weight (g) of material collected per cm^2 surface area from six artificial media exposed at the near-surface level for varing time periods

Observation date	May 26	June 12	July 3	July 25
Exposure period (days)	41	58	79	101
Media				
Wood	0.1292	0.0928	0.0738	0.0504
Steel	0.1447	0.2547	0.2258	0.1296
Plexiglass	0.1931	0.0896	0.0763	0.0439
Copper-nickel alloy	0.0000	0.0000	0.0026	0.0039
Concrete	0.1192	0.0665	0.0506	0.0350

The steel plates were extensively fouled after 58 days of exposure. Diatoms, green algae, barnacles, and mussels were observed attached to the surface after 101 days of exposure. Extreme surface decay was observed; as much as 70 per cent of the surface area was covered by a coat of rust. The percentages of the surface areas covered with rust and the dry weights of material from the plates taken from various depths showed that surface degeneration (rusting) was greatest in the near-surface waters and decreased with depth. Dry weights of 0.2258 g/cm^2, 0.0433 g/cm^2, and 0.0171 g/cm^2, respectively, at the surface, middle, and bottom levels were observed after 79 days of exposure. The dry weights presented in Table 12-2 for steel generally exceed those of other media tested, but a high proportion of these weights was from rust and not from biological accumulations.

Plexiglass was included as an artificial medium because of its hard, smooth, nondegenerate surface. These properties influenced the magnitude of fouling accumulation but did not greatly alter species composition. Diatoms and algae were attached to the medium surface in the same abundance as on other media tested, but barnacles were substantially less than observed on wood and concrete. Mussels were completely absent from the plexiglass medium.

A wood substratum was observed to be colonized by colonial diatoms and barnacles after an exposure period of 30 days during June. The wood substrata at the bottom of the Skagit Island location showed a maximum barnacle density of 51.5 *B. crenatus*/cm^2 after 79 days of exposure, or a 100 per cent surface area cover. No wood borers were observed associated with the media.

The concrete substrata appeared to have nearly the same fouling properties as the wood substrata . Both media were heavily colonized by diatoms at the surface level and were the only media colonized by *B. crenatus* at the bottom level. At the Skagit location, barnacles achieved 100 per cent cover (density 63.0 barnacles/cm^2) of the concrete media. However, at the middle and surface levels barnacles had a colonization ratio of 3:1 on the concrete and wood, respectively. A similar colonization ratio between the wood and concrete panels could have existed at the bottom level but for the limitation of available surface for setting. *B. crenatus* did not occur as secondary set on any test panel. Bay mussels, *M. edulis*, had set at a density of 0.4 mussels/cm^2 at the surface level after 101 exposure days (April-July) and at a density of 1 per cm^2 by November (223 days). Only slight surface deterioration

of the concrete substratum was observed after continuous submergence for eight months.

Anthracite was the only "natural" substratum tested. Because of the irregular forms of this substratum no quantitative measurement was made other than simple counts of macrofauna. After 60 days of exposure at the surface (May 26-July 25), the population included one large *B. crenatus* (8.30 mm) and nine *M. edulis* (1.0-1.5 mm length). The anthracite was extensively covered with colonial diatoms and algae. This was the most heavily fouled of the substrata tested.

12.3.2 Intertidal Fouling

Colonization on concrete test plots positioned at various tide levels in the intertidal zone of Kiket Island was observed. The principal algal species observed colonizing the concrete fouling plates were *Fucus distichus* and *Ulva lactuca*. The dominant zoofouling organisms included the acorn barnacle *B. glandula* and the bay mussel, *M. edulis*. A detailed examination of the vertical and seasonal distribution of intertidal algal species is presented by Houghton (Section 7.0).

Colonization was extremely low during the winter and early spring. Test areas scraped in December remained virtually uncolonized until the following May. Colonization during late May was extremely rapid, and within one month the mean barnacle density at all intertidal levels had reached maximum (Fig. 12-3). Subsequent to this peak a general decrease was noted, and at the end of six months (late November) the mean densities had begun to stabilize. Intraspecies competition among the organisms for the limited area in which to grow led to the substantial decrease in density following the early maximum.

The effect of tidal level is important with respect to the duration of exposure to the sun (desiccation) and the abrasion resulting from wave action. The results are effectively seen when the densities of barnacles present at all tidal levels are compared.

At the +2- and 0-ft levels, desiccation had a considerable effect on limiting the abundance of barnacles. No barnacles successfully set at the +2-ft level. Wave abrasion was also evident at this higher tidal level. Heavy siltation and diatomaceous growths predominated at the -4 ft level,

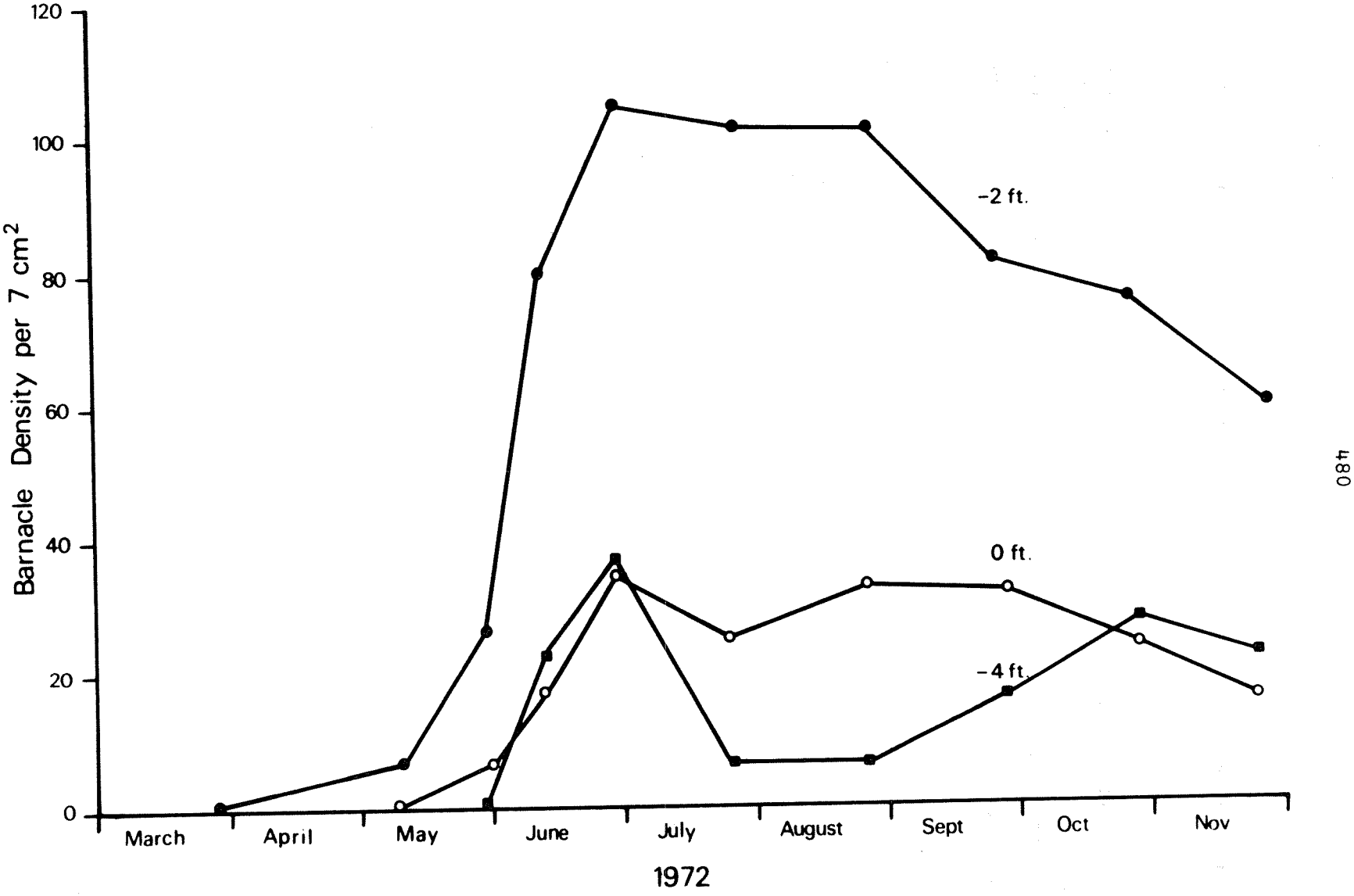

Fig. 12-3. Mean density of *Balanus glandula* attached to concrete substrata exposed in the intertidal zone of Kiket Island (tidal level relative to msl).

effectively limiting successful colonization. Colonization and subsequent growth of *B. glandula* were greatest at the -2-ft level. Exposure to the sun was a less significant factor in survival at this tidal level than at the upper levels. Also, moderate wave action limited the silt/diatom buildup, thus exposing primary setting areas acceptable for colonization by barnacles and mussels.

Colonization by the bay mussel, *M. edulis*, was predominant at the -2-ft tidal level, where maximum density was $1.3/cm^2$. Mussels were present at a lower density at the 0- and -4-ft levels. They were observed to attach primarily in the late summer and fall (July-October); a few individuals were observed in April and May.

12.3.3 Seasonal and Vertical Distributions of Fouling Organisms

The seasonal distribution of the major groups of sessile fouling organisms is presnted in Fig. 12-4. These generalizations are based on data collected during the past one and one-half years on intertidal colonization by sessile organisms and on an eight-month study of subtidal fouling. Subtidal vertical distribution is presented in Fig. 12-5. These results pertain to the seasonal and vertical distribution of organisms present on artificial substrata exposed in the vicinity of Kiket Island. Comparable results were obtained by DePalma (1966) for Admiralty Inlet. A discussion by group follows.

Subtidal diatoms established themselves exclusively on fouling plates placed near the surface or at mid-depth. The spores of some species were present all year, but growths occurred predominantly from early spring through midsummer. Colonial diatoms rapidly colonized fouling plates submerged during this time period but only partially colonized plates exposed during the winter.

Intertidal diatoms existed predominantly at the -4-ft tidal level and partially at the -2-ft level. Wave action was considerably less at these levels compared with that at higher levels. Another contributing factor was the lesser severity of desiccation at the lower levels compared with that at the 0- or +2-ft tidal levels.

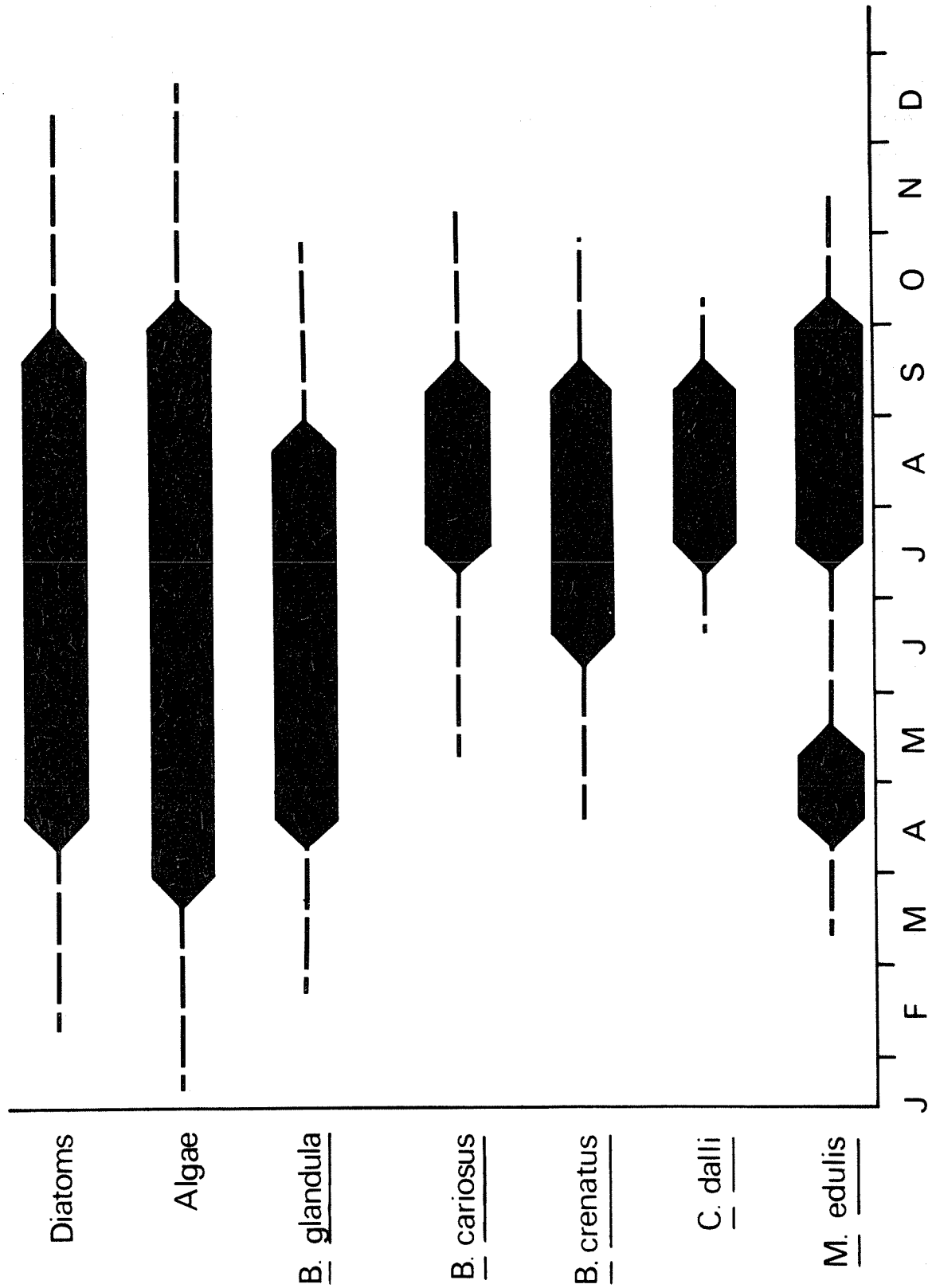

Fig. 12-4. Seasonal distribution of predominant subtidal and intertidal fouling organisms.

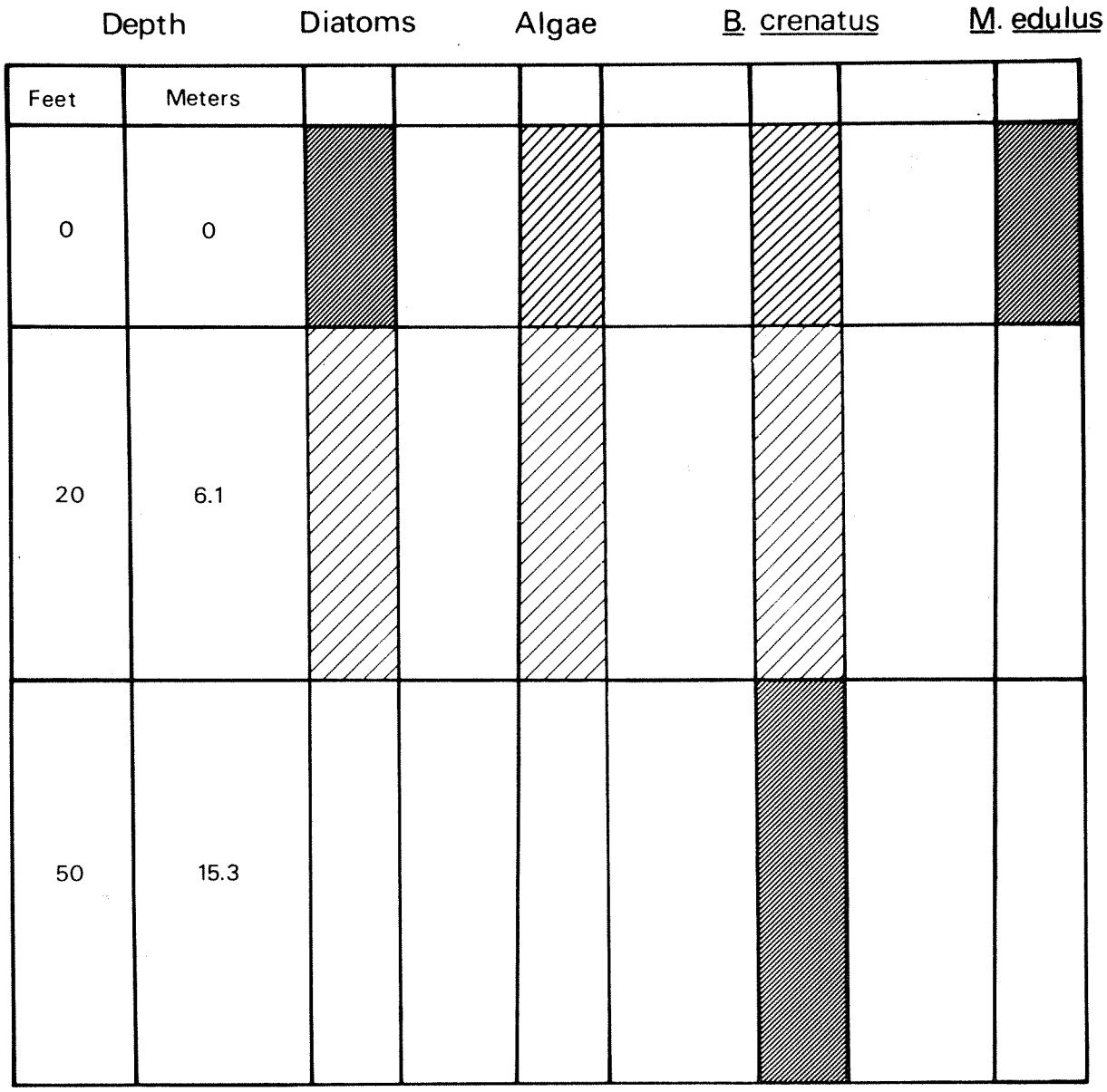

Fig. 12-5. Vertical distribution of major subtidal fouling groups.

The most abundant of all colonial diatoms and the first to appear on the settling plates were those of the genera *Melosira*. *Navicula* and *Fragilaria*, as well as a large number of unidentified species, also colonized the subtidal plates.

Four dominant algal forms were observed to colonize the artificial substrata. *F. distichus* and *U. lactuca* predominated intertidally, whereas *Ulotrix* sp., *Cladophora* sp., and *U. lactuca* were present subtidally. The seasonality of marine algae was evident in the extensive algal cover present in the spring and summer and the substantially decreased algal abundance during the fall and winter.

Barnacles of the genus *Balanus* were present and set all year, but the abundance of larvae varied greatly with season. Maximum setting occurred during late spring (April-June) and again in early fall (mid-August-October). Subtidal studies, although incomplete, showed setting of *B. crenatus* from April through November with a peak occurring in late July and early August. Intertidally, *B. glandula* set from February through November. The absence of set during December and January does not indicate that setting was completely absent since the lack of observed set may be attributed to low densities of spat. Peak setting for *B. glandula* occurred during late spring and early fall. Settlement by *B. cariosus* and *Chathamulus dalli* was generally maximum during August and September and sporadic from May through November.

B. glandula comprised approximately 90 per cent of the intertidal barnacle population; *B. cariosus, B. crenatus,* and *Chathmalus dalli* were secondary species. *B. crenatus* dominated the subtidal population, and *B. cariosus* and *B. glandula* occurred occasionally.

The mussels present belonged to the species *M. edulis*. Settlement occurred predominantly from early August through October and less predominantly during April and May. Even though a substratum is available for colonization by mussels, it appears that prior colonization by diatoms, algae, and barnacles is necessary for the establishment of mussel set. Cleaned substrata were exposed intertidally and subtidally during early fall along with substrata with an established community present, and only on those plates already fouled was colonization by mussels observed. Coe (1932) reported the same phenomenon and concluded that the smooth surface of nonfouled substrata did not afford suitable attachment for the byssus of young mussels.

In the subtidal, mussels were observed exclusively attached to plates placed near the surface. Intertidally, however, they colonized at the 0-, -2-, and -4-ft levels relative to msl.

12.4 SUMMARY AND CONCLUSIONS

1) The sessile communities characteristic of artificial substrata in the intertidal and subtidal zones on Kiket Island, Washington, are described.

2) Seasonal variations in settlement and abundance were noted for the three major fouling groups: diatoms, barnacles, and mussels.

3) The nature and composition of the substratum material determined to a high degree the rate of colonization and the types of colonizing organisms. The degree of decay and biofouling was least for copper-nickel alloy and progressively greater for plexiglass, wood, steel, concrete, and anthracite. Decay was greatest at the near-surface levels, decreasing in severity with increasing depth.

4) Observations of species progression indicate that colonization by some early forms (bacteria or diatoms) was essential for the establishment of communities dominated by either barnacles or mussels.

5) Subtidal species diversity was greatest at the near-surface level, and the dominant forms were colonial diatoms and mussels. Acorn barnacles of the species *B. crenatus* were the only biofouling organisms observed at the bottom level.

6) The average compensation depth during June and July was 5.5-6.1 m relative to mean sea level, based on observations of the vertical distribution of sessile algae.

7) The dominant intertidal fouling organisms were the acorn barnacle *B. glandula* and the bay mussel, *M. edulis*. Maximum abundance of both species occurred at the -2-ft tidal level.

8) Studies carried out with static test panels are applicable in gathering information related to seasonality, vertical distribution, and species progression in the development of a climax community but can give only a limited indication of the magnitude or growth rate of fouling organisms inhabiting a continuous-flow cooling system.

13.0 QUALITATIVE EVALUATION OF MARINE ZOOPLANKTON

by

B. Leistikow

13.1 INTRODUCTION

Marine zooplankton is a complex assortment of small, drifting animals. These animals represent most of the phyla and range in stage of development from eggs and larvae to mature adults. Their movements are directed primarily by water currents and tides. Zooplankton is composed of herbivores (e.g., most calanoids and cyclopoid copepods) and primary carnivores (e.g., chaetognaths and some calanoids). It is grazed on, in turn, by the planktophagous fish, such as herring, smelt, and juvenile salmon. Most fish and benthic invertebrates, including the economically important forms of crabs, clams, and fish, begin their lives as planktonic eggs and larvae. It is evident that any complete study of a marine ecosystem must include a thorough investigation of the zooplankton population. However, this is a formidable undertaking which involves complex taxonomic identification and quantification of very large populations that are in continual flux in response to season, time of day, salinity, tide, and many other factors.

Such a study was beyond the scope of this project. Objectives of this investigation were to examine a few selected samples taken near Kiket Island and to establish a partial checklist of zooplankton species with a ranking of the relative abundance of each. Helpful taxonomic references were noted along with the relative ease of identifying members of the major groups. A reference species collection was assembled. This information will be useful in any future zooplankton studies in Northern Skagit Bay.

13.2 MATERIALS AND METHODS

Four of the samples collected off Dewey Point (Fig. 6-1, section 6.0) for the study of pelagic fish eggs and larvae were examined. Two were collected in the summer (July 28, 1971) and two were collected in the winter (February 17, 1972). One sample was taken at ebb tide and one at flood tide

on each date. All were from daytime hauls taken vertically from bottom (approximately 40 m) to surface.

Each sample was placed in a petri dish and then scanned under a binocular dissecting microscope. The relative abundance of each major category of zooplankton was noted. A reference collection was then made of the types of organisms by sample for later classification. All organisms were stored in 2-dram vials with a 5 per cent solution of salt water and Formalin. Each organism was identified to species or the nearest possible category, and a reference collection was assembled. Since time was limited, effort was concentrated on the more abundant and economically important groups (especially crab larvae and calanoid and cyclopoid copepods).

13.3 LITERATURE

Very few papers are available on the composition of the zooplankton of this region. Wailes (1929) compiled the first species list of British Columbia marine zooplankton from pre-existing studies, which he did not cite. His list includes species of every major category of zooplankton with the exception of larval forms. The University of Washington Department of Oceanography (1954) compiled a simplified list of species for Puget Sound together with some information on their relative abundance and seasonal distribution. Hebard (1956) studied the seasonal composition and vertical distribution of zooplankton at three stations near Seattle. He discussed the calanoid and cyclopoid copepods in detail and by species, but other categories, however, only by major grouping, e.g., crustacean larvae, amphipods, etc. Damkaer (1964) discussed in detail the vertical distribution of copepods in Dabob Bay. He listed 22 calanoids, 5 cyclopoids, 2 harpacticoids, and 1 monstrilloid copepod. A very helpful paper by Fulton (1968) lists all the species of adult zooplankton from the water surrounding British Columbia, with notes about their abundance by depth and season. He includes simplified keys to some of the groups. Most importantly, for each species he lists taxonomic references. Taxonomic and other helpful references used in this study are listed in the bibliography.

13.4 RESULTS AND DISCUSSION

The major categories of zooplankton differed in relative abundance in the samples, as shown in Table 13-1. Calanoid copepods were the most numerous of the categories in the four samples. The cyclopoid copepods were also relatively abundant. The cladocerans, ostracods, larvaceans, harpacticoids, pelycepods, and teleost larvae were less abundant but were consistently present in all four samples. Coelenterates (medusae and siphonophores) and crustacean larvae increased greatly in the summer samples. The hyperiid amphipods were numerous only in the summer ebb-tide sample. Other groups were rare (< 10 per sample) and did not appear every sample. Few major differences were noted between the ebb tide and the flood tide samples.

The species composition of the samples is detailed in Table 13-2. Organisms belonging to rare species were counted. Other species were ranked according to relative abundance in each sample by a system of plus signs. References used to identify each species are listed. A discussion by major categories follows.

13.4.1 Medusae

The maximum number (13) of medusae was found in the sample taken at summer flood tide. Although not numerous compared to the calanoid copepods, they accounted for much of the biomass of that sample because of their large size. Six types of medusae were observed, none of which could be identified within the time available. The most numerous form, T 1, resembled *Phialidium gregarium*, which Fulton (1968) lists as an abundant form on the surface during the summer. In his list of references Fulton does not include a key by Waters (1960), a helpful reference when used in conjunction with an illustrated one.

13.4.2 Siphonophora

Siphonophores were not numerous in these samples, although they are cited as the most abundant coelenterates by Hebard (1956). *Mugiaea atlantica* is listed by Fulton (1968) as a rare deep-water form.

Table 13-1. Major categories of zooplankton found and their relative abundance (+++ = predominant, ++ = abundant, but not predominant, + = scarce, of less than 10 per sample)

Phylum	Major category	Sample taken Feb. 17, 1972		Sample taken July 28, 1971	
		Ebb tide	Flood tide	Ebb Tide	Flood tide
Coelenterata	Coelenterata			+	++
Annelida	Polychaeta	+	+	+	
Arthropoda	Cladocera	++	++	++	++
	Ostracoda	+	+	+	+
	Calanoida	+++	+++	+++	+++
	Cyclopoida	++	++	++	++
	Harpacticoida	+	+	+	+
	Monstrilloida			+	
	Mysidacea	+		+	
	Cumacea	+		+	
	Isopoda				+
	Amphipoda	+	+	++	+
	Euphausia	+	+		
	Crustacean larvae	+	+	++	++
Mollusca	Gastropoda	+	+	+	
	Pelycepoda	+	+	+	+
Chaetognatha	Chaetognatha	+	+		+
Chordata	Larvacea	++	++	++	++
	Teleosti	+	+	+	+
Unknown	Eggs	+		+	+

Table 13-2. Species composition of the zooplankton samples (numbers indicate total sample counts of rare species; plus signs indicate more frequent species that were not counted: +++ = predominant, ++ = common, but not predominant, + = uncommon)

	Reference	Sample taken Feb. 17, 1972		Sample taken July 28, 1971	
		Ebb tide	Flood tide	Ebb tide	Flood tide
Coelenterata					
Medusae T1					5
T2					1
T3					3
T4					1
T5					3
T6				1	
Siphonophora					
Hugiaea atlantica Campbell	Totton & Frasier (1955)			1	1
Unidentified T1					1
Ctenophora					
Pleurobranchia pileus (Müller)				1	
Annelida					
Polychaeta					
Phalacrophorous sp.	Huus (1953)		1		
Tomopteris septentrionalis Quatretages	Berkeley & Berkeley (1948)			2	
Syllid (Fam.) larvae	Newell & Newell (1930)			1	
Unidentified larvae		1	7	1	
Arthropoda					
Crustacea					
Cladocera	Fulton (1968)				
Evadne nordmanni Loven		++	++	++	++
Podon leucarti Sars		++	++	++	++
Ostracoda					
Conchoecia alta minor McIlardy	McIlardy (1964)	1	2	1	
Conchoecia elegans Sars	Smith (1952)			1	1
Copepoda					
Calanoida	Brodskii (1950)				
Acartia clausi Giesbrecht					+
Acartia longiremis (Lilljeborg)		++	++	++	++
Calanus pacificus Brodskii		++	++	++	++
Centropages mcmurrichi Willey				+	+

Table 13-2. Species composition of the zooplankton samples (numbers indicate total sample counts of rare species; plus signs indicate more frequent species that were not counted: +++ = predominant, ++ = common, but not predominant, + = uncommon) - continued

	Reference	Sample taken Feb. 17, 1972		Sample taken July 28, 1971	
		Ebb tide	Flood tide	Ebb tide	Flood tide
Epilabidocera amphitrites (McMurrich)				2	+
Euchaeta japonica Marukawa		2			
Eurytemora americana Williams	Brodskii (1950);Fulton (1968)			++	++
Metridia lucens Boeck		+		+	+
Pseudocalanus elongatus (Boeck)		+++	+++	+++	+++
Tortanus discaudata (Thompson & Scott)		++	++	++	++
Unidentified T1			+		+
Cyclopoida	Olson (1948);Sars (1918)				
Corycaeus anglicus Lubbock		4	+	++	++
Oithona helgolandica Claus		+		+	
Oithona spinstrosis Claus		++	++	++	++
Unidentified T1			+		+
Harpacticoida	Lang (1948); Sars (1911)				
Diosaccus spinatus Campbell				2	1
Harpacticus uniremis Krøyer		1	1	2	
Parathalistris sp.		1	1	1	
Petidiidae (Fam.)				1	
Rhynchothalistris helgolandica Claus			1	1	
Tisbe furcata (Baird)			3	1	
Monstrilloida				1	
Nauplii T1		3			
T2				++	
T3				++	++
Cirrepeda (larvae)					
Nauplii				++	++
Cypris T1				++	++
T2				++	++
Mysidacea		1		+	
Cumacea	Hart (1930, 1969)				
Cumella sp.		1			
Lamprops carinata Hart				1	
Leucon fulvus Sars				1	
Isopoda				1	
Amphipoda	Barnard (1969);Sars (1895)				

Table 13-2. Species composition of the zooplankton samples (numbers indicate total sample counts of rare species; plus signs indicate more frequent species that were not counted: +++ = predominant, ++ = common, but not predominant, + = uncommon) - continued

	Reference	Sample taken Feb. 17, 1972		Sample taken July 28, 1971	
		Ebb tide	Flood tide	Ebb tide	Flood tide
Calliopius laeviusculus (Krøyer)				1	
Cyphocaris challengeri Stebbing	Gurjanova (1951)				1
Orchomene anaquela Barnard	Barnard (1964)	1			
Podoceridae (Fam)				1	
Parathemisto pacifica Stebbing	Bowman (1953)	3		13	++
Parathemisto sp.	Bowman (1953)			1	
Tiron sp.				1	
Unidentified			2		
Eucarida					
Euphausiacea					
Euphausia pacifica Hansen	Fulton (1968)	1	1		
Decapoda (larvae)					
Brachyura	Aikawa (1929, 1933, 1937)				
Cancer sp.		+	+	++	++
Cancer (magister/productus)	Mir (1961); Poole(1966); Trask (1970)	+	+	++	
Hemigrapsis oregonensis (Dana)	Hart (1935)			+	
Inachidae (Fam.)			+		+
Lophopanopaeus bellus Stimpson	Hart (1935)				+
Pinnotheridae (Fam.)				++	++
Penaeidea/Caridea (larvae)					
Crangonidae (Fam.) T1	Newell & Newell (1963)			++	++
T2				++	++
T3				++	++
Unidentified T1				++	
T2				++	
T3				++	
Anomura (larvae)	Newell & Newell (1963)				
Paguris beringanus (Benedict)	Hart (1937)		2		
Paguris sp.				3	
Mollusca					
Gastropoda					
Muricidae (Fam.)		1		1	
Unidentified larvae			3	2	
(Pteropoda)		1			

Table 13-2. Species composition of the zooplankton samples (numbers indicate total sample counts of rare species; plus signs indicate more frequent species that were not counted: +++ = predominant, ++ = common, but not predominant, + = uncommon) - continued

	Reference	Sample taken Feb. 17, 1972		Sample taken July 28, 1971	
		Ebb tide	Flood tide	Ebb tide	Flood tide
Pelycepoda	Keene (1963)				
Hiatella sp.				1	
Musculus sp.		1			
Unidentified larvae		2	2	4	1
Chaetognatha					
Sagitta elegans Verill	Fulton(1968)	7	+		+
Chordata					
Larvacea	Buckmann (1945)				
Oikopleura dioica Fol				+	+
Oikopleura sp.		+	+	+	+
Teleostei (larvae)					
Ammodytae					
Ammodytes hexapterus Pallas		1	4		
Cottidae U14					1
Gobiidae					
Clevelandia ios (Jordan & Gilbert)				1	
Pleuronectidae					
Psettichthys melanostictus Girard					1
Stichaeidae					
Chirolophus sp.		1			
Lumpenus sp.			1		
Phylum(s) undetermined					
Eggs T1		+		+	+
T2					+
T3				+	

13.4.3 Ctenophora

Pleurobranchia pileus occurred abundantly in the catches of midwater tows made for fish collections. Only one was taken in the plankton samples, and it was in fragments. Liley (1958) illustrates this ctenophore as one of the three ctenophores found in British Columbia waters.

13.4.4 Polychaeta

Very young polychaete larvae are nearly impossible to identify, but one larvae had developed enough of the adult characteristics that it could be classified as belonging to the family Syllidae. Adult pelagic polychaetes were also present in small numbers, one species of which, *Tomopteris septentrionalis*, is listed by Wailes (1929), Fulton (1968), and Berkeley and Berkeley (1948). *Phalacrophorus* sp. (Fam. Phyllodocidae, Subfam. Iospilinae) was not recorded from this region by previous researchers. The specimen found in the February 17 flood tide sample most resembled *P. pictus* as described by Muus (1953).

13.4.5 Calanoida

Ten species of calanoids were identified from Brodskii (1950), all of which, except *Eurytemora americana*, had been listed by Damkaer (1964). An eleventh species, probably a pseudocalanoid, was found but could not be identified. *Pseudocalanus elongatus* made up approximately 70 per cent of the calanoids in the samples. *P. elongatus* was one of the major calanoids in Damkaer's (1964) samples from Dabob Bay. *Acartia longiremis, Calanus pacificus* and *Tortanus discaudata* were the next most abundant copepods in the Skagit Bay samples. *Eurytemora americana* was found only in the summer samples. Its occurrence was interesting because marine forms of this genus are confined to brackish waters (Brodskii, 1950). Its presence in these samples indicates a freshwater runoff through Deception Pass. All other calanoids were uncommon or rare in the samples.

Damkaer (1964) completed a review of the literature on every copepod species he found in Dabob Bay. His thesis should be consulted for information dealing with distribution and temperature, depth, and salinity preferences for each species.

13.4.6 Cyclopoida

Oithona spinstrosis was the most common cyclopoid in the samples. *O. helgolandica* was found only rarely. The reverse was true of Damkaer's (1964) Dabob Bay samples. More *Corycaeus anglicus* occurred in the summer samples than in the winter samples, but they did not reach the level of abundance of *O. spinstrosis*. All cyclopoids were identified from Olson (1949).

13.4.7 Harpacticoida

Six species of harpacticoid copepods were found, two of which, *Parathalistris* sp. and *Rhynchothalistris helgolandica*, had not previously been reported in this region. All species were identified from Lang (1948) and from illustrations by Sars (1911).

13.4.8 Monstrilloida

One monstrilloid copepod was found, and it was not identified to species. Fulton (1968) lists four monstrilloid species, all of them of the genus *Monstrilla* and all of them rare in occurrence.

13.4.9 Copepod and Cirrepede Larvae

All types of copepod nauplii (except one species that was found only in the winter), cirrepede nauplii, and cypris larvae were abundant in the summer samples but did not occur in the winter samples. Although references are available for the identification of these larvae, they are very difficult to identify; therefore, identification was not attempted.

13.4.10 Mysidacea

Ten species of mysids that occur in marine inland waters are listed by Fulton (1968). The few mysids in these samples were not identified; however, *Neomysis awatschensis* was found to be abundant in North Skagit Bay and studied in another part of this investigation.

13.4.11 Amphipoda

The hyperiid amphipod *Parathemisto pacifica* was the most common amphipod in these samples. It was also listed as an abundant species by Fulton. *Calliopius laeviusculus* and *Cyphocaris challengeri* are two gammerid amphipods frequently found in zooplankton samples. *Orchomene (anaquela)* and the podoceran are benthic forms, and their presence indicates that the plankton net may have sampled the bottom.

13.4.12 Decapod Larvae

None of the researchers who have compiled lists of species for the Puget Sound region have attempted to identify any of the decapod larvae. Enough literature is available, however, that nearly all of these larvae can be identified to family and some to genus and species. Since the Dungeness crab, *Cancer magister*, is the most economically important decapod in the area, effort was concentrated on the crab (brachyuran) larvae.

A list of all the crabs classified according to family, genus, and species was compiled from data obtained from the intertidal, otter trawl, and benthic samples taken around Kiket Island. It was assumed in the identification of the crab larvae (zoeae) that these crabs were the only contributors to the zoeal population, although it is possible that crabs of other species exist in the area or that occasional oceanic zoeae are carried in through Deception Pass. The expected zoeal forms for each of the brachyurun families represented around Kiket Island were then determined from Aikawa (1929, 1933, 1937). Zoeae found in the samples were identified to family. Genus or species was determined from available taxonomic literature on the zoea of local crabs. The crab species of the Kiket Island area and the taxonomic literature are listed in Table 13-3.

Ease of identification varied. The zoeae of *Cancer* spp. could be readily identified. The zoeae of *C. magister*, the Dungeness crab, could not be distinguished from the zoeae of *C. productus*, the red rock crab. The zoeae of *C. oregonensis*, the hairy crab, have not yet been described. Since this species is even more closely related to *C. magister* than to *C. productus*, it is possible that *C. oregonensis* larvae are also indistinguishable from *C. magister* larvae.

Table 13-3. The crab species of North Skagit Bay by family with taxonomic references to the zoeae

	Reference
Atelecyclidae	
Telmessus cheirogonus Tilesius	
Cancridae	
Cancer gibbulosus DeHaan (scarce)	Aikawa (1937)
C. gracilis Dana	
C. magister Dana	Mir (1961); Poole (1966)
C. oregonensis Dana	
C. productus Randall	Trask (1970)
Grapsidae	
Hemigrapsis nudus (Dana)	Hart (1935)
H. oregonensis (Dana)	Hart (1935)
Inachidae	
Oregonia gracilis Dana	
Pugettia gracilis Dana	Aikawa (1929)(genus only)
P. producta Randall (scarce)	
Chorilia longipes Dana	
Scyra acutifrons Dana	
Majidae	
Chionoectes bairdi Rathbun	Aikawa (1937) (genus only)
Hyas lyratus Dana	Aikawa (1937) (genus only)
Pinnotheridae	
Pinnixa littoralis Holmes	Aikawa (1937) (genus only); Hyman (1924) (genus only)
P. occidentalis Rathbun	
P. schmitti Rathbun	
P. faba (Dana)	
Scleroplax granulata Rathbun	
Xanthidae	
Lophopanopaeus bellus Stimpson	Hart (1935)

13.4.13 Mollusca

Five of the gastropod larvae and five of the clam larvae were too young to identify. The older larvae that had developed more of the adult characteristics could be identified. Two muricid (family) gastropods were found, one in the winter and one in the summer. A mollusc with a shell resembling the pteropod *Limnacea helicina* was found but could not be classified. The pelecypods that were identified to genus looked like small adults of those groups. It is doubtful that these pelycepods were planktonic, but were instead stirred up from the bottom by water currents or by the plankton net.

13.4.14 Larvacea

Oikopleura dioica was the only larvacean that could be identified in these samples. Classification of *Oikopleura* sp. was made difficult by Formalin-caused erosion of the specimens.

13.4.15 Teleostei

All fish larvae had been removed from the samples and are treated in section 6.0 of this report. A list of all the species found in these samples is included in Table 13-2. For discussion about these larvae, see the discussion in this report about pelagic fish eggs and larvae.

13.4.16 Eggs

All of the eggs in those samples were smaller than fish eggs. No attempt was made to identify them.

14.0 THE POTENTIAL OF HEATED WATER IN SALMONID MARICULTURE

by

T. J. Northup and Q. J. Stober

14.1 INTRODUCTION

Research by the Fisheries Research Institute and the National Marine Fisheries Service in salmonid aquaculture has demonstrated the potential in high-density salt-water rearing of salmon in floating enclosures (Mahnken, Novotny, and Joyner, 1970; and Stober and Salo, 1971). At all the aquaculture projects maintained by these organizations on Puget Sound, however, the lower ambient water temperatures brought on by winter have caused a marked decrease in growth and conversion rates of food to body weight. Therefore, the principal objective of the heated water mariculture experiment was to test the possibility that the use of artificially heated water will enable fish culturists to maintain relatively high growth and conversion rates through the winter months. The secondary objective was to compare the growth and conversion rates of fish reared in heated water with those of fish reared concurrently under ambient water temperatures. The experiment was conducted on a small scale so that close observation could be made of disease and general behavior problems associated with a warm water environment. A further consideration was the cost involved in continuously heating sea water in a single-pass system.

14.2 MATERIALS AND METHODS

The experiment was conducted at the Kiket Island marine laboratory described by Stober (1972). The fish chosen for rearing were chinook salmon (*Oncorhynchus tshawytscha*) from the fall 1971 brood fish taken from Finch Creek, Washington, and spawned at the Hoodsport Hatchery of the Washington Department of Fisheries. Hatching occurred in early February, 1972. The fry were moved to the University of Washington Big Beef Creek facility on April 24, 1972, then to the Kiket Island offshore rearing pen on May 24, 1972.

On October 13, 1972, the chinook salmon were transported to the laboratory in aerated 35-gal plastic garbage cans. In the laboratory the fish were tranquilized with a solution of MS 222, measured for over-all length, and weighed

in groups of five (mean weight = 70 g). The fish were held in an aerated recovery tank in groups of fifty until they regained equilibrium. One hundred-fifty each were introduced into two rearing tanks. This density closely approximated that in the offshore pen. All 300 fish recovered and appeared in good condition.

The fish were held in two light-green fiberglass cylindrical tanks (Heath-Techna model 169) with capacities of approximately 28 ft^3 (4-ft dia x 2.25-ft depth). Water was introduced at the bottom of each tank through a 1.5 inch diameter PVC pipe and drained through a centrally located 2-inch diameter PVC standpipe. The tanks were covered with screens; originally these were plastic window screens with 16 meshes to the inch, later they were 1-inch knotless-nylon-mesh screens. Feeding was conducted through the screens.

Light was provided initially by two 2-ft fluorescent lights (Duro-Test Vita-Lite, 20 w), but was reduced soon after the experiment was begun by removal of one light from each fixture. Lights were left on only during normal working hours, which corresponded closely to daylight hours throughout most of the study.

The food consisted of Oregon Moist Pellets, initially 1/8-inch diameter in size and 1/4-inch in diameter after October 18. In addition, 1/8-inch diameter terramycin-treated (TM-50) pellets were fed for disease control.

Feedings were at 0800, 1100, 1400, and 1700 hr daily. The feeding rate maintained in the offshore pen, 3 per cent of the average weight per fish per day, was continued in the laboratory. Because of the shallow depth of the tanks, the food was introduced slowly in order to give the fish a good chance to ingest the pellets before they reached bottom.

After 3 days of acclimation of the fish, heated water was introduced into the test tank for the first time on October 17, 1972. The test temperature was gradually elevated to 17 C on October 21. The temperature was maintained as closely as possible to this level until December 7, when ambient water temperatures began dipping below 7 C. Then the test temperature was allowed to drop to 10 C above ambient. The maximum temperature of heated water was limited to either 17 C or 10 C above ambient, whichever required less heat, for the purpose of preventing thermal stress (Stober and Salo, 1971).

Measurement of environmental parameters was an important part of this experiment. Water temperatures were monitored continuously by means of an ARA model ET100/SD20 scanning thermometer and ARA model 400 strip chart recorder. Temperature probes were located in each tank 6 inches from the surface and 6 inches from the bottom. In addition, at each feeding the following data were recorded: temperature (thermometer), salinity (Kahlsico model RS5-3 salinometer), and flow rate (timed rate of flow through drain). Dissolved oxygen content was measured through the modified Winkler technique at the first and last feedings on each day from samples siphoned from the tanks. Dissolved oxygen was supplemented with compressed air, introduced at the bottom of each tank through 1/4-inch ID Tygon tubing. Dissolved oxygen samples and flow rate measurements were taken during feeding, but thermometer and salinometer readings were delayed until after the feedings in an effort to avoid disturbing the fish.

Dead and nearly dead fish were removed from the tanks at feeding times. Mortalities were weighed, measured, and examined for degree of scale loss, possible injury, or disease. The fish were preserved either by freezing or by immersion in 10% Formalin.

Once each day waste food, feces, and detrital material brought in by the water supply were siphoned from the tanks. The latter was composed primarily of sediment, algae, and parts of animals. A few live tadpole sculpin (*Psychrolutes paradoxus*, Gunther) were found and removed. Minimal material was brought into the test tank by the water supply since it was filtered before it was passed through the heat exchanger.

The heated water experiment was terminated on December 22. The waterflow through the heat exchanger was then shut off and ambient water was reintroduced into the test tank. For the next three days the test fish were observed for obvious signs of distress or shock.

14.3 RESULTS AND DISCUSSION

14.3.1 Growth

The average lengths and weights of the chinook salmon at the periodic measurements on November 13 and again on December 26 are shown in Table 14-1. From October 13 to November 13 the test fish gained slightly in average

Table 14-1. Statistics of the chinook salmon cultured at ambient temperature (control) and in heated sea water in the Kiket Island laboratory

Date		Number of fish		Total weight (g)		Average weight (g)		Density (lb/ft^3)		Average length (mm)		Per cent scale loss	
		Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control
10/13/72		150	150	10,917	11,003	72.78	73.35	0.86	0.87	191.8	193.0	~10	~10
↓	Died	5	42			54.10	59.27					~65	~50
↓	Lost	3	5										
11/13/72		142	103	10,425	7,192	73.42	69.02	0.82	0.57	197.2	195.0	~35	~55
Removed		50	6	3,504	316								
Remaining		92	97	6,921	6,876	75.23	70.89	0.54	0.54	198.4	195.0		
↓	Died	34	67			54.20	51.26					~80	~85
↓	Lost	1	4										
12/26/72		57	26	4,672	1,866	81.96	71.77	0.37	0.15	205.6	198.2	~60	~75

weight, whereas the controls had an average weight loss of nearly 5 per cent. Both groups gained in average length. From November 13 to December 26, the test fish increased in weight by 9 per cent, whereas the controls increased by 1 per cent but still did not regain their original weights.

Meaningful calculations of growth and conversion rates are virtually impossible. While some fish were eating well and growing, the overall trend was a deterioration in condition and death, especially among the controls. Large amounts of food were eaten by fish that lost weight and later died.

The only substantial gain in weight noted was 6.73 g/fish among the test fish or a growth rate of 0.156 g/fish/day, from November 13 to December 26. The feeding rate for these fish, at 3 per cent, was 2.26 g/fish/day; thus the conversion rate was 14.5 g of food to 1 g of body weight.

On December 26 the test fish ranged in weight from 40.7 g to 148.0 g, and the controls from 28.9 g to 132.1 g. The fish were not weighed individually at the beginning of the study, but the size ranges were of the same order of magnitude.

14.3.2 Condition

During the first month mortalities were relatively few among the test fish (Fig. 14-1). The heated tank appeared to have a greater carrying capacity than the control tank; therefore on November 13, fifty fish were removed from the test tank so that the densities would be equalized. By December 26 the remaining test fish had been depleted by a 35 per cent mortality. The controls suffered nearly 30 per cent mortality during the first month, and the remaining fish over 70 per cent mortality by December 26. Total mortality among the controls reached 77 per cent during the study period. The same symptoms were manifested by both test and control fish.

An outstanding feature of the condition of the fish was the degree of scale loss. Stresses from the initial handling and from overcrowding apparently caused substantial scale loss, especially among the controls. At the first monthly examination scaling was not extensive among the test fish; but the stress from handling during this time apparently caused considerable additional scaling, as mortalities occurred among them, too, at an increased rate.

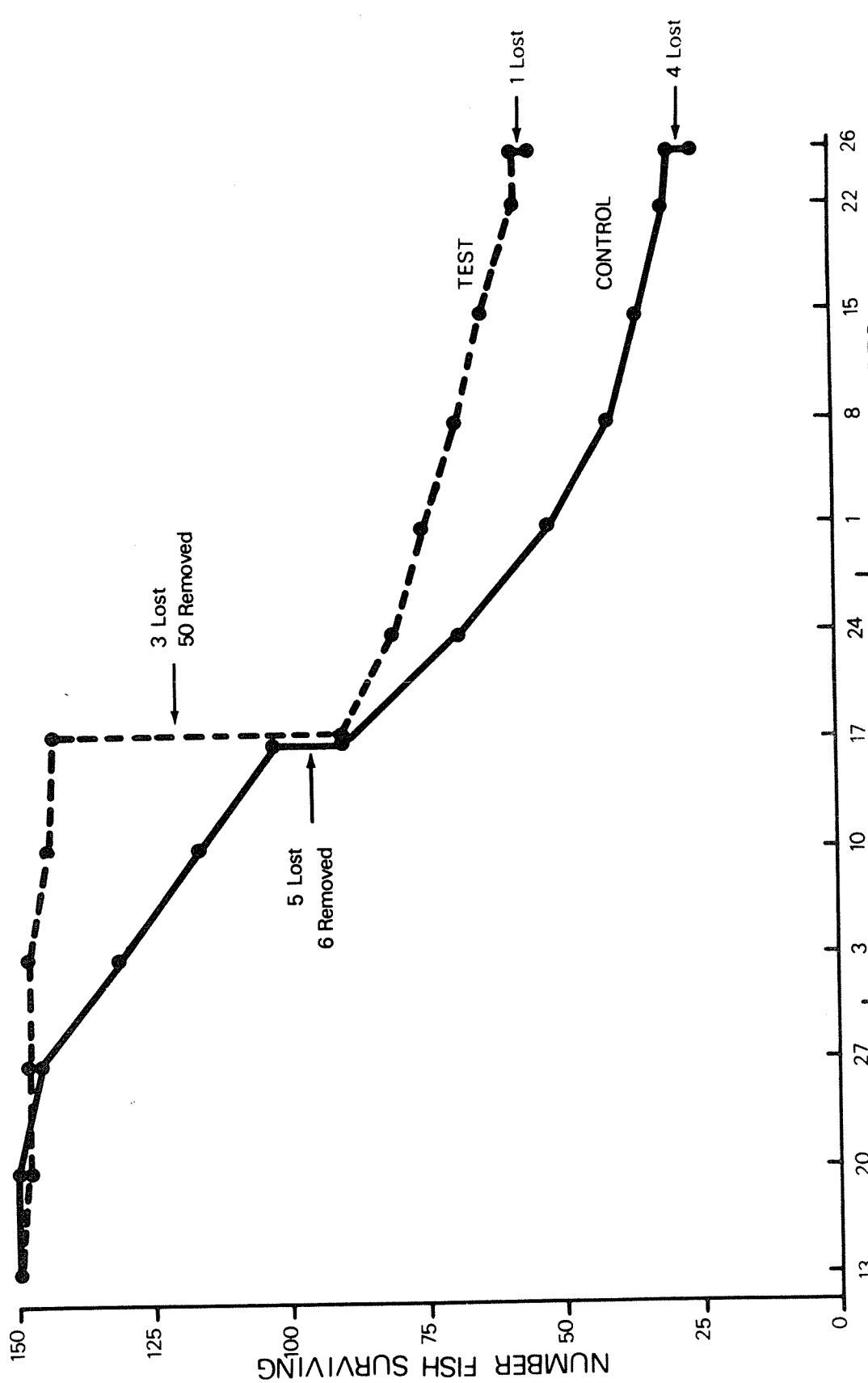

Fig. 14-1. Number of surviving chinook salmon and those lost or removed from the test and control groups during the course of the experiment.

Fish afflicted with severe scale loss have difficulty in maintaining osmotic balance and lose their resistance to bacterial infection. Death is brought on by the osmotic loss of fluids from body tissues and poisoning from toxic levels of magnesium ion in the blood. At high levels magnesium ion causes blockage of the myoneural junctions, bringing on lethargy, paralysis, and death (Smith et al., unpublished). Many of the fish, especially the controls, exhibited symptoms characteristic of high magnesium ion concentration. Most or all eventually died.

Of the total mortalities, 32 per cent showed ulcerous sores. Nearly all of these sores were on the caudal peduncle. In 58 per cent of the mortalities and 11 per cent of the survivors tail erosion was severe enough to prevent overall length measurement, and in many others tail erosion was evident though to a lesser degree. In addition, in 22 per cent of the mortalities the skin and flesh had been eroded from the nose.

There was considerable loss of weight due to a number of factors. The average weight of the dead fish was 54.45 g, whereas the average weight of the live fish initially was 73.07 g. The factors responsible for the large weight loss were lack of feeding, osmotic loss of fluids, and loss of tissue from tail erosion or ulcerous sores. Many of the surviving fish lost weight from the same conditions.

Seven mortalities (one test fish, six controls), all of which died during the first three weeks of the experiment, were examined for disease. Two of the controls showed evidence of *Vibrio* infection. Of those fish surviving the study, ten from each tank were examined and were found to show no sign of bacterial infection. More extensive microbiological examination of mortalities would have been desirable; however, there were difficulties in getting fresh specimens to suitable facilities. Terramycin-treated pellets were introduced during alternate feedings for ten-day periods (Wood, 1968), but the treatment had no discernible influence on mortality rates.

14.3.3 Behavior

There were obvious behavioral differences between test and control fish. During the first month the controls appeared stressed and very excitable. They swam somewhat randomly very near the surface, many with their dorsal fins breaking the water surface. At the same time the test fish were closely schooled and swam about 1 ft beneath the surface.

After the controls became somewhat depleted in number they did not frequent the surface as much but lay lethargically on the bottom in increasing numbers. The behavior of the test fish did not change markedly during the study except that a few, like the controls, appeared lethargic.

The controls were generally poor feeders. Large amounts of waste food collected on the tank bottom. The test fish fed more actively. The smaller fish and those that had become weaker frequently appeared intimidated by larger fish when attempting to feed.

Both groups showed a tendency to leap against the covering screens at times. They sometimes hit the screens with enough force to move them. Some fish probably lost scales and may have suffered skin breaks from impingement on the screens.

A total of thirteen chinook salmon was "lost" (Table 14-1). Three are known to have leaped out while the screens were being removed for examination or the tanks were being cleaned. These were lost through the laboratory floor drain. Presumably the rest escaped in a similar manner, but were undetected.

At the termination of the experiments the test temperature was dropped suddenly from 17 C to 7.7 C. No immediate distress was apparent among the fish. Over the subsequent three days of observation the only noticeable behavioral change was some decrease in activity and in feeding. There were no mortalities.

14.3.4 Environment

The light intensity and color and size of the tanks in the laboratory may have been detrimental to the fish and contributed to their stress, as they had previously been acclimated to a much larger, deeper, and darker pen. Even though light intensity was minimized as much as possible early in the study, it was found to be considerably higher than that in the offshore pens.

Ambient water temperatures ranged from 10.5 C on October 17 to 7.2 C on December 15 (Fig. 14-2). Initially the water heater was set at 130 F to maintain 17 C. When ambient water temperatures dropped to 7 C or below, it became necessary to keep the heater at 165 F to maintain adequate heat. Maintenance of this temperature around the clock resulted in a fuel consumption of about 35 to 40 gal of No. 2 diesel per day (to supply about 18 gal/min of heated water).

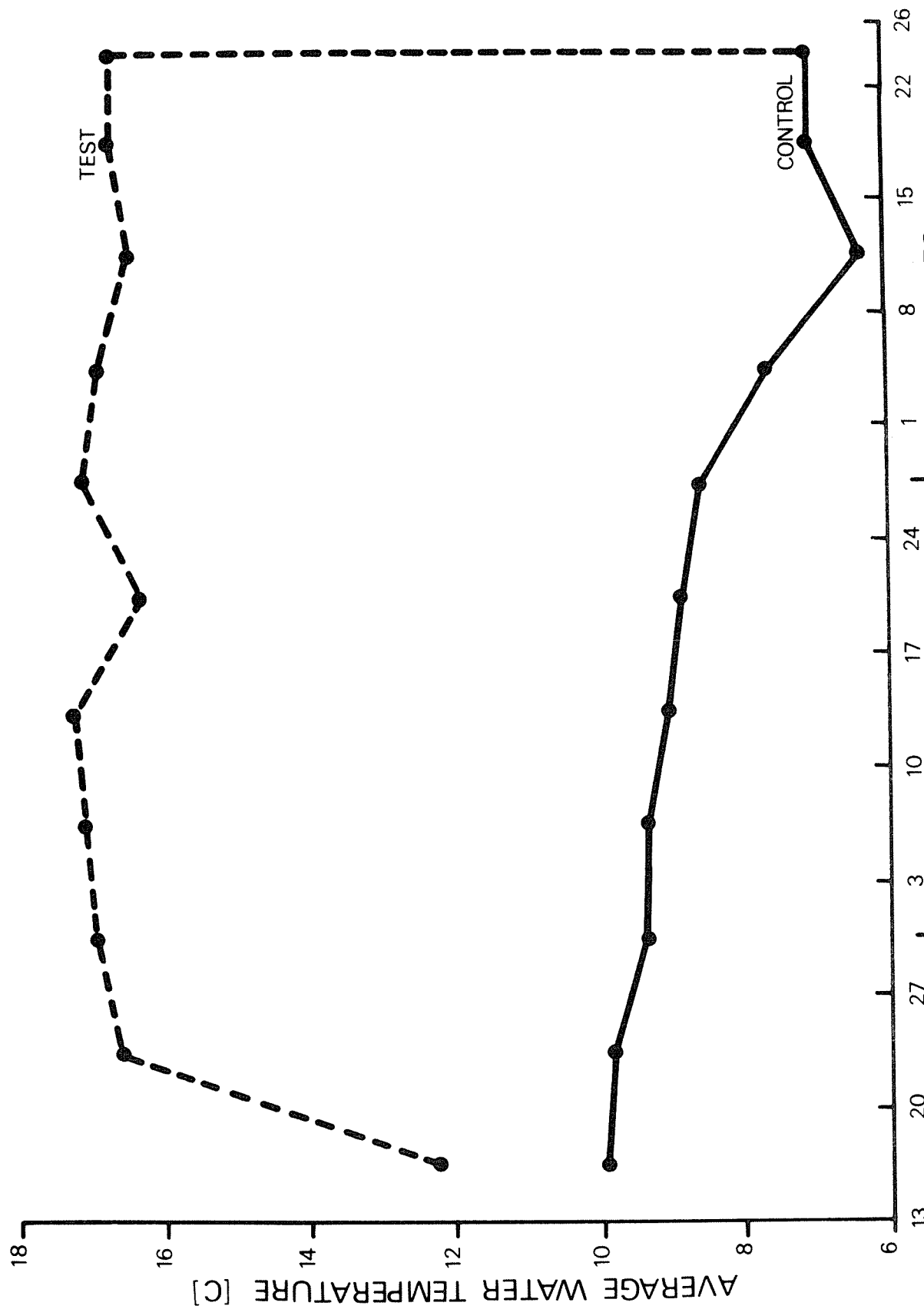

Fig. 14-2. Weekly average test of control water temperatures at which chinook salmon were cultured.

The rate of flow of ambient water was kept as close as possible to that of the heated water (Table 14-2), but precise control was difficult due to frequent clogging of the gravel filter.

When it was necessary to cut off water to the tanks, the fish were held for periods of well over 1 hr with no apparent ill effect. Aeration was increased during these periods.

The overall trend in salinity was determined mainly by the amount of runoff from the nearby Skagit River (Fig. 14-3). The lowest readings were taken at low tide, when the river was at freshet. Salinity readings over the tidal cycles sometimes varied over 4 °/oo. Salinity was consistently slightly higher in the test tank than in the control.

Dissolved oxygen levels were low when the study began and may have contributed to the stress on the fish (Fig. 14-4). As the weather became cooler, windier, and rainier, dissolved oxygen content rose steadily. This trend was the reverse of that observed with salinity.

14.4 SUMMARY AND CONCLUSIONS

Although the original objective was not achieved, several interesting observations were made. The test fish did not maintain their summertime growth and conversion rates. The relatively large size of the fish and small size of the rearing tanks led to overcrowding, which affected the condition of the fish. The constraints imposed by the volume of heated water available and the limited size of the rearing tank require that further experimentation be conducted on smaller fish. A similar experiment is being repeated with chum salmon.

Some valuable information was acquired in regard to the potential of heated water for salmonid mariculture. Comparative data indicate that the chinook salmon in heated water did considerably better than the control fish from the standpoints of growth, survival, and overall condition. Observations indicated that the test fish were apparently under less stress than the controls and fed much more actively.

The chinook salmon used were not accustomed to the existing laboratory facilities, having been previously reared under much different conditions in the offshore pen. In addition, too many were used. After the first month,

Table 14-2. Weekly average flow rates maintained through the test and control tanks during the course of the experiment

Week ending	Test tank	Control tank
October 20	18.27	18.43
27	17.78	18.11
November 3	17.97	18.11
10	18.87	18.65
17	18.63	18.72
24	18.75	18.95
December 1	18.16	18.89
8	17.92	18.56
15	17.53	17.57
22	18.11	17.86

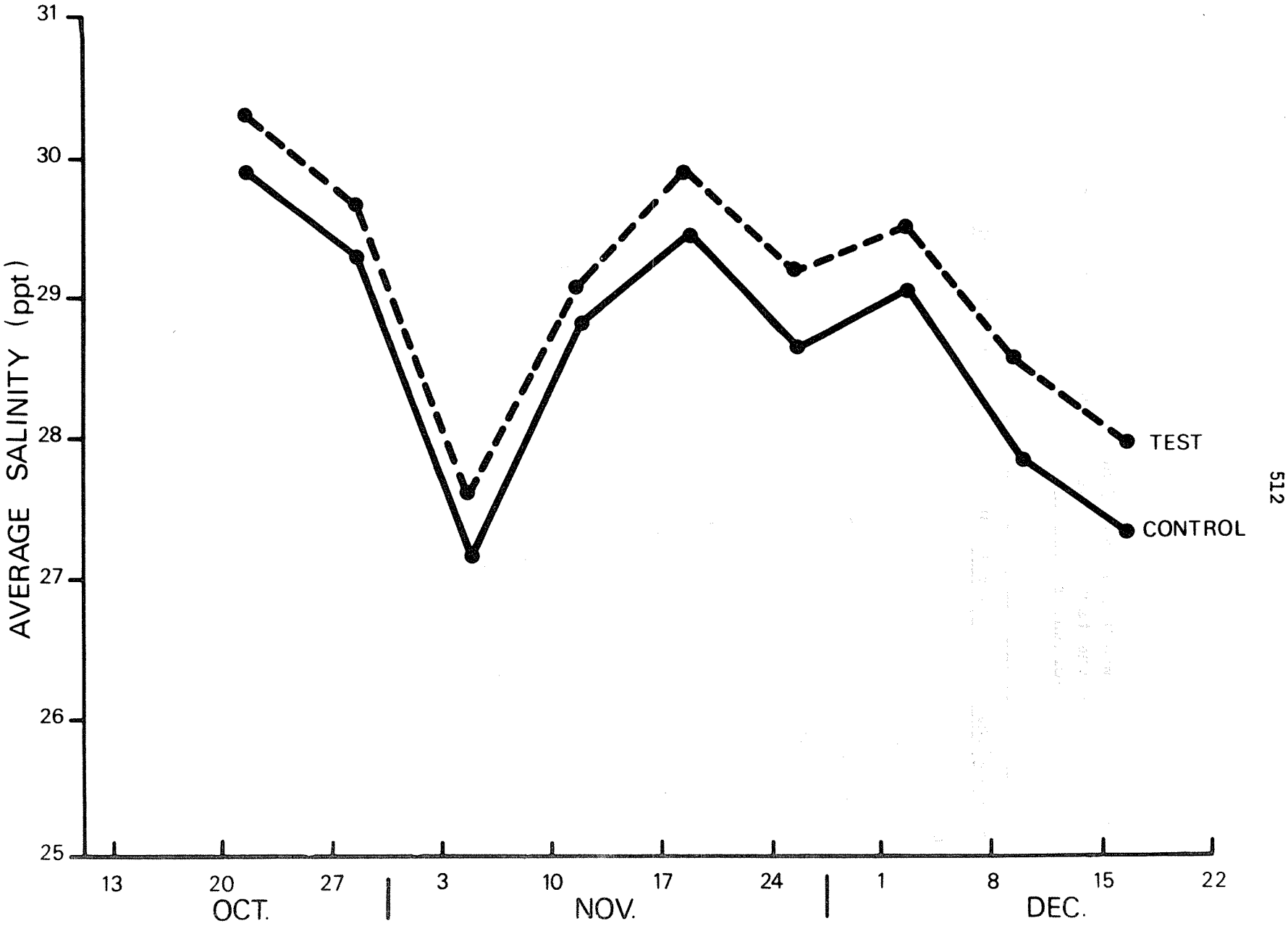

Fig. 14-3. Weekly average salinity measurements in test and control tanks during experiment.

Fig. 14-4. Weekly average dissolved oxygen concentrations in test and control tanks during experiment.

when their numbers had been reduced, some growth occurred, but the fish were already in poor condition from scale loss. Mortalities in both tanks were very high, and many of the survivors were very thin.

More definitive results could probably be obtained by replicating the experiment but using much smaller fish previously acclimated to shallow, lighted tanks. More of the smaller fish could be raised without overcrowding, and growth would be much greater in relation to initial size.

Fuel consumption figures indicate that the use of preheated water, such as the cooling water from a nuclear power plant, would be the only way to make warmwater mariculture feasible. In this study less than 20 gal/min of heated water was used and about 2,000 gal of heating fuel was consumed in 74 days. The retail cost of this fuel at $0.193 per gallon averaged about $5.20 per day. Unless a more efficient heating method is found, the fuel costs alone would prohibit a commercial application of heat.

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